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Movements and Decline of Large Quoddy Herring

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ABSTRACT

Development, beginning in 1876, of heavy fishing for "sardines", the yearling herring available in and near Passamaquoddy Bay between New Brunswick and Maine, was followed by decrease in numbers of older fish. The very local and very fat "Quoddy River" herring disappeared promptly. The immense accumulated stock of large spawning herring lasted ten years or more after recruitment was thus greatly reduced. This stock was being coincidently shifted from the Quoddy region, apparently owing to reduced rainfall.

The normal seasonal shifting of these fish is between the outer side of Grand Manan Island in summer and near the mainland in winter. In midsummer of 1877, their numbers at Grand Manan began to diminish and for four years remained very low. They were as abundant as ever in winter near the mainland, but farther from shore and more numerous eastward. They appeared inside the Reversing Falls of the Saint John River, whose outflow goes to Grand Manan, in all four years of their scarcity at Grand Manan. Large herring appeared in unexampled numbers at Quaco, east of Saint John, from 1878 to 1881 and then declined. A movement across the Bay to Nova Scotia became evident by a marked rise in Annapolis County in 1881, and, farther in, in Kings County in 1882, in each case lasting for four years and not going beyond the mouth of Minas Channel. These fish seemed to make the circuit of the Bay, affecting catches at its head and on to the New Brunswick side, with return to the Saint John outflow by 1884. Farther out, other lots reached the Nova Scotian coast from Digby to Cape Sable in 1881, remained high for four years and then declined. By 1891, catches everywhere were down to a very low level, indicating exhaustion of the stock.

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INTRODUCTION

During the last half of the nineteenth century, there was a major transformation in the herring population of the Bay of Fundy, of which the tempo was too slow for it to be understood by those who brought it about. It can be appreciated in historical perspective. The century was one of rapid increase in the settlement of the continent with consequent sharp rise in demand for fish as food. The Fundy herring were rather readily available in large quantities as they were taken mainly with gill-nets and weirs. The latter are fixed traps of brush or netting supported by stakes, which are driven into the bottom or even built up from ballasted cribwork or from sleepers bolted to the rock bottom. Tidal rise and fall of the water permit them to be built and emptied of fish rather easily at low tide and yet to fish in deep water and perhaps far from shore at high tide. In this way deep-water fish, brought to the place by strong tidal currents, are trapped and held for ready removal at the low-water slack, without current and with the water in the heart of the weir as shallow as its location permits. Such traps, peculiarly adapted to the Bay of Fundy with its high tides, were in early use by the Acadian French on the Nova Scotian side, and were adopted in the region of greatest herring abundance on the New Brunswick side about 1820. They have since then been developed into extremely efficient engines for taking various kinds of fish as well as all sizes of herring. They are particularly suitable for herring and have permitted the development of more effective use of the herring stocks of the region than have those of any other region. This is clearly shown by the marked decline in the numbers of large herring that followed the development of methods of handling and of a market for the smaller fish.

The region near the mouth of the bay on the west side, where the herring are most abundant, may be called the Quoddy region since Passamaquoddy Bay, Quoddy River, West Quoddy, East Quoddy are local names in the heart of the region. It is on the west side of the outer part of the Bay of Fundy and may be considered to extend from Saint John to the outer end of Grand Manan Island, a coastwise distance of 60 miles. It extends inland through an archipelago (West Isles) to Passamaquoddy Bay and the St. Croix River, a distance of about 15 miles. The coast of Maine borders this inland extension on the west and prevents its being entirely Canadian. The easternmost port of the United States, Eastport, serves to handle a large part of the fish destined for the principal markets which are in that country. Through narrow, tortuous passages and over rocky shoals, the heavy tides of the region with amplitude of 20 to 25 feet mix the coastal water from the Gulf of Maine very thoroughly with a very large amount of fresh water discharged into the region from various rivers from the Saint John to the St. Croix on the international boundary. These drain an immense area in New Brunswick, Maine and Quebec. The mixed water flows out into the Gulf of Maine and southwestward along the coast. This is the background for what seems to be the most concentrated and intense fishery for fish grown locally that exists in the world. From 40 to more than 100 millions of pounds of herring alone are now taken annually from the Canadian part of the region.

The official fishery statistics provide the main facts from which conclusions will be drawn. Their defects have been kept in mind. As evidence, their value can be judged from the extent to which data collected independently corroborate each other in showing a common phenomenon. Only with such corroboration can they be accepted. There is confidence when the picture revealed is a consistent one.

During the period dealt with, conditions were favourable for the fishery to show the distribution of the large herring. There was a steady market for them as pickled in barrels, both for home consumption and for export. They could be readily taken with gill-nets along the coast and their preservation was comparatively simple as long as barrels and salt were kept on hand. In addition, the reporting of statistics had been in progress sufficiently long to be working well, but not so long that interest in recording details had waned, as it did later.

THE DECLINE OF LARGE HERRING

For this story, many facts now seen as desirable were not seen at the time as important and were not recorded. The story is, however, in the main sufficiently clear from the facts and reports that are at hand. Long search among old documents and papers would doubtless improve it considerably, but may not be required. The official reports and the published results of investigations, on which reliance is placed, should be the most dependable sources of information. The transformation can be most readily appreciated by contrasting 1850, before it began, with 1950, after the new regime has been in operation for more than seventy years. In 1850, Moses H. Perley of Saint John, H. M. Emigration Officer for handling new settlers, investigated the fisheries of the Bay of Fundy for the Colonial Government of New Brunswick. His report (1851) gave a very good picture of the use then made of the herring, from which come the following details for the Quoddy region of greatest abundance and proximity to markets in the United States.

In 1850, as now, the main part of the fisheries was in the waters of Charlotte County, New Brunswick. It was largely for large spawning herring to be salted in barrels, but also for herring that had not quite reached spawning size to be hard-smoked and packed in boxes. Small amounts of herring, particularly small fish, were used for bait and manure, but the latter use was considered reprehensible. The large were taken in gill-nets (hence called net-herring) chiefly on the spawning grounds for four miles along the shore around the southern end of Grand Manan between July 15 and September 15. They came in enormous numbers, coating ropes, lines and nets with spawn, so that in the clearing of the nets the decks of the vessels would be ankle-deep with spawn. Over 100 fishing vessels operated in this stretch within half a mile of shore in depths less than ten fathoms, the tops of the nets being set from the surface to as much as five fathoms deep. There was open war between the settlers and the nonresidents (mostly from the United States), with much destruction or theft of gear, in the competition for good berths for their net moorings. This spawning ground was shortly thereafter closed to fishing and guarded. The somewhat smaller fat

herring for smoking (hence called stringing herring or stringers) were taken in brush weirs, of which there were about 60, 27 at Grand Manan and 21 at Campobello where most of this size of herring were to be taken. The small herring were not in demand, except for bait, for which they were frequently taken by dipping at night with a light (called "driving" or "torching"). Slightly more than 10,000 barrels were salted and about 70,000 boxes were smoked, which would require about 4,000,000 pounds of fresh fish. Those caught by outsiders and those taken to Eastport and Lubec on the Maine coast may have increased the total to 10,000,000 pounds.

In 1946, the most recent year for which statistics are available at time of writing, 109,794,000 pounds of herring of all sizes were landed from the waters of Charlotte County, of which 95,414,400 were classed as "sardines", that is, too small for salting or smoking, although not necessarily so. They were for the

TABLE I. Small herring in cwt. landed in Charlotte and Saint John Counties, N.B., from 1870 to 1946, as reported in the fishery statistics under the headings "bait", "fertilizer", "manure", "guano" (pomace), or "sardines". 1 bbl. = 200 lb.; 1 ton of guano = 5,000 lb.; 1 case (100 cans) of sardines = 40 lb.; 1 hogshead = 1,000 lb. For years 1880 to 1887 quantities for E. Charlotte are taken as bbls.

	'0	'1	'2	'3	'4	'5	'6	'7	'8	'9
187'	48,500	45,000	32,750	24,325	125,100	11,000	50,200	53,338	48,800	32,170
188'	157,934	172,530	155,400	220,620	282,520	309,596	366,700	226,360	197,230	250,734
189'	239,704	382,084	279,314	220,692	294,818	418,526	204,552	344,244	388,300	476,512
190'	241,018	523,834	353,604	404,686	705,921	722,786	531,162	581,358	637,044	545,565
191'	391,617	826,232	587,041	314,050	632,988	695,900	675,660	571,074	536,155	514,136
192'	426,248	374,614	565,370	285,618	575,880	361,294	355,761	369,918	573,844	541,994
193'	325,029	191,278	158,853	277,627	397,952	381,656	526,224	374,427	385,347	656,644
194'	453,640	859,449	616,808	766,524	787,239	655,097	952,302			

TABLE II. Medium herring in cwt. landed in Charlotte and Saint John Counties, N.B., from 1870 to 1946, as reported in the fisheries statistics under the headings "canned" (herring), "boneless", "smoked" or "kippered". 1 case = 70 lb.; 1 box = 10 lb.; 1 lb. or can = 2 lb.

	'0	'1	'2	'3	'4	'5	'6	'7	'8	'9
187'	10,820	?	57,134	49,764	39,960	59,394	49,470	51,755	60,730	68,353
188'	47,509	98,856	107,095	113,461	179,040	131,060	107,495	147,700	144,550	261,210
189'	131,119	224,298	289,760	97,608	166,231	173,820	199,348	140,875	182,365	182,899
190'	52,504	131,353	92,227	42,326	96,426	98,680	133,226	85,178	32,240	86,766
191'	24,234	151,381	151,426	112,814	49,617	142,710	124,620	19,899	23,726	78,955
192'	178,994	39,558	70,496	4,960	56,015	88,185	182,049	32,811	66,767	115,167
193'	58,788	66,077	73,882	111,677	96,129	97,819	93,221	70,796	67,875	86,487
194'	121,600	89,158	105,093	144,801	106,001	95,721	123,970			

most part taken in weirs, of which there were 330, but only 46 at Grand Manan and 37 at Campobello. That means that most of them were in the inner waters where there were scarcely any in 1850. Of the total amount of herring, 71,733,200 pounds were sold fresh and salted, mostly to canneries in Maine. The remainder made 725,186 cases of canned fish, 3,145,400 pounds of smoked, 3,351 barrels of pickled, 310,600 pounds of vinegar-cured fillets, 11,050 barrels for bait, 47,571 gallons of oil, and 2,535,300 pounds of scales for pearl essence.

The course of the fishery for seventy years from the time that statistics began to be collected regularly after Confederation is shown in Figure 1. The three main sizes have been separated—the large net-herring used for pickling or for the fresh or frozen trade, the medium stringers for smoking and the smaller fish that are largely canned as sardines. Compilation of these figures has revealed quite a few discrepancies between statements concerning the catches and the

TABLE III. Large herring in cwt. landed in Charlotte and Saint John Counties, N.B. from 1870 to 1946, as reported in the fisheries statistics under the headings "fresh", "frozen", "salted" or "pickled". 1 bbl. of salted or pickled = 300 lb.; 100 fish = 40 lb.; 1 cwt. dry salted = 125 lb.

	'0	'1	'2	'3	'4	'5	'6	'7	'8	'9
187'	155,653	?	102,336	134,595	230,247	245,250	293,994	273,159	243,588	273,780
188'	270,450	201,990	330,731	275,640	240,540	247,935	221,019	231,722	232,697	176,117
189'	106,673	56,128	55,340	68,315	124,720	71,394	165,585	112,443	225,629	231,168
190'	45,438	77,414	63,120	40,779	41,421	31,590	31,812	7,580	10,811	14,966
191'	6,345	19,195	5,172	52,994	4,641	3,855	74,578	4,773	11,781	2,480
192'	13,105	735	5,644	19,518	23,886	62,587	34,569	83,468	42,870	35,843
193'	45,076	41,546	32,310	7,071	88,490	85,215	68,895	66,886	27,950	64,997
194'	56,667	57,942	104,324	48,343	32,744	25,581	62,285			

TABLE IV. Total herring in cwt. landed in Charlotte and Saint John Counties, N.B. from 1870 to 1946, as reported in the fisheries statistics. From 1870 to 1909, the sum of "small" (Table I), "medium" (Table II), and "large" (Table III), but from 1910 to 1946 the sum of "caught and landed", weights of "herring" and "sardines". 1 bbl. "sardines" = 200 lb.

	'0	'1	'2	'3	'4	'5	'6	'7	'8	'9
187'	174,973	378,618	192,220	208,684	395,307	315,644	393,664	378,252	353,118	374,303
188'	475,893	473,376	593,226	609,721	702,100	688,591	695,214	605,782	574,477	688,061
189'	477,496	662,510	624,414	386,615	585,769	663,740	569,485	597,562	796,294	890,579
190'	338,960	732,601	508,951	487,791	843,768	853,056	696,200	674,116	680,095	647,297
191'	421,349	996,866	749,764	480,065	689,896	842,040	874,863	584,919	633,643	529,076
192'	629,482	420,863	646,117	305,096	655,762	488,326	571,879	504,472	718,958	703,787
193'	455,589	347,534	278,622	409,266	598,247	585,791	710,082	513,533	483,397	820,328
194'	654,806	1,016,758	823,027	911,246	899,009	774,759	1,116,914			

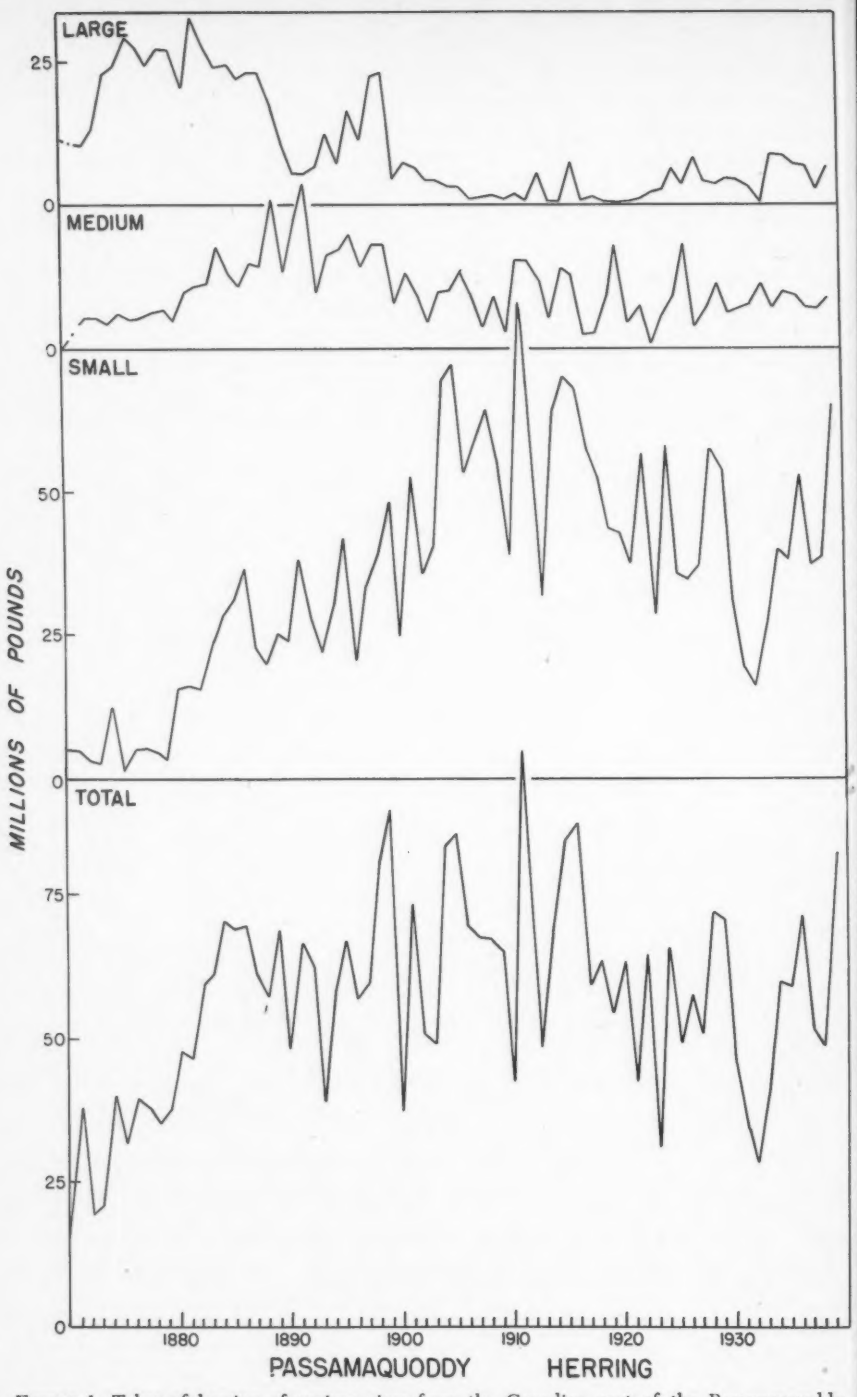

FIGURE 1. Takes of herring of various sizes from the Canadian part of the Passamaquoddy region of the Bay of Fundy (Saint John to Grand Manan) from 1870 to 1939.

figures published. Also, changes in the methods of reporting the catches without record of the basis for the new calculation have made it difficult to reduce the catches to a common basis for comparison. In spite of all the errors that have probably been made, there would seem to be no doubt of the main change that occurred in the latter half of the 19th century. The data for Figure 1 are given in Tables I to IV, where the conversion factors used in bringing the official figures to a common basis of landed weight in hundreds of pounds are given. These factors are those that have recently been used by the Department of Fisheries. Some of the older statistics were reported in units not recently in use, and factors for these were obtained by consulting the Department in 1933.

It will be seen (Figure 1) that with the development of an intensive fishery for the small herring from 1879 to 1905, the medium herring at first increased rather sharply in quantity and then dropped somewhat to a lower level that was nevertheless higher than the original one, and that, with rather sharp fluctuations, has been maintained. The large herring, on the other hand, dropped sharply about 1890 and to a still lower level after 1900. This low level has been maintained since with considerable fluctuations, and it is only about a quarter as great as the original one. In spite of the very much greater numbers of individuals that are being taken, because the principal size now is less than one-eighth that before the the sardine industry began, the total take rose to double the original level and this has been well maintained with fluctuations for over sixty years, with some amounts in the 1940's even higher than the previous high of 1911. Great reduction of the stock of large herring has not affected the supply of young.

PRESENT ABUNDANCE OF SMALL HERRING

The present great abundance of the young herring and scarcity of the large can best be appreciated in comparison with the great abundance of the large before the sardine industry began, as described by those who were following it and whose background was the view that only large herring were worth considering. For 1871, Overseer W. B. McLaughlin of Grand Manan reported at the end of November: "Netting has been constant and without interruption in Grand Manan for more than a year, and they have been abundant for bait and other purposes. Since the expiration of the close time at Southern Head, thousands of barrels have been taken. I have known as high as fifty barrels to a boat taken in a single night, and now, while I write, the waters of Seal Cove are swarming with herring, in fact the supply is greater than the demand". For 1873, Overseer Andrews of St. Andrews reported: "There were about 45 vessels from different parts of the Bay of Fundy netting herring for two and a half months in the winter and spring . . . in the inner bay of Passamaquoddy", and for the same year Overseer Best of Beaver Harbour reported: "Herring fishing has been remarkably good this season, in fact better than ever known in any previous year. The principal fishing was done from the 1st of January to the 1st of March, when fish were sold in a frozen state to American traders. After the latter date, herring still continued plentiful, but fishing was not pursued as there was no demand in the market".

There is evidence that intensive fishing for the sardines made them, as well as the medium or stringing herring, more abundant. This does not follow from the fact that more were taken. Also the fishery facts are not very reliable for showing abundance since so many factors affect both the quantities of fish removed and the amount of gear or effort used in fishing. The number of weirs operated in Charlotte County doubled very quickly with demand for sardines, and the new ones were built chiefly where sardines were most plentiful. Later, the number redoubled. It is perhaps indicative of great increase in the numbers of sardines that the take of sardines per weir on the whole went up during this development from less than 400 barrels with the first doubling to nearly 500 barrels when there had been sufficient time for adjustment to the redoubling. With strong demand and not many fewer weirs (367 versus 420 in Charlotte County) the take per weir from 1940 to 1943 averaged 877 barrels as compared with 492 barrels from 1910 to 1913. There are three lines of evidence for increase in abundance of sardines. One is that heavy removal during a long season would make them seem less numerous if their number remained constant, since their availability would decrease as more were taken out early in the season. For 1880, 1881 and 1882, in each year the quantity taken was three times what had been taken previously. Then with increasing quantities taken for four years, reports for 1883 were: "This increased consumption of small herring does not yet seem to have lessened the supply" (Venning); "weir fishing was very good" (Best); "sardines have been more than usually plentiful" (Brown). A second line of evidence is that they became so numerous as to overflow from the main region for them, which is inside and at the mouth of Passamaquoddy Bay, by appearing in larger numbers at Grand Manan, the locality for medium and large herring. For 1882, McLaughlin reported for Grand Manan that "sardine herrings have been taken in small quantities in several weirs, the first for many years". They were taken there regularly thereafter, and in 1888 he stated: "Sardine herring are beginning to be more generally utilized, and if prices rise to their former level, this business will form an important item in our industries". In 1890 he reported that "the herring ran small, or of sardine size". A third line of evidence tends to relate increase in small herring to decrease in medium and large herring, which more or less compete with them for food. In 1900, the catch of large herring dropped greatly and never recovered. The take of small herring was greater in 1899 than ever before and, perhaps as a result, the take of medium herring dropped in the following year. In 1901, the take of small herring was even greater than in 1899, and the take of medium herring again dropped in the following year and more still in the second following (1903). Then in 1904 and 1905 the take of small herring rose to unprecedented heights, more than a third higher than ever before. In 1904, with an unprecedented catch, Overseer Billings of St. Andrews reported: "Many times this season, the sardine weirs were full of herring which were not taken out, there being no demand for them". The evidence is strong that heavy removal of sardine herring progressively increased the numbers of sardine herring. The first increase may have been a result of decreasing the number to become medium herring far within the sardine area.

Decrease in large herring, which came slowly, permitted more medium herring to survive. A second marked increase of the sardines resulted when, with the large herring for the most part eliminated, intensive fishing for the sardines reduced the numbers of medium herring generally and gave very full scope for food from the Gulf of Maine to pass the parts of the region populated by large and medium herring and reach far inland where the sardines are congregated.

CHANGES IN OCCURRENCE OF LARGE SPAWNING HERRING

Although the development of the sardine industry in the Quoddy region had a marked effect on the numbers of spawning herring related to that region, there is no evidence that it affected the numbers of large herring outside the region which are doubtless derived from local small herring rather than from a common stock. The quantities of herring now taken on the Nova Scotian side of the Bay of Fundy run about the same as those of the 1870's before the sardine industry developed, and the fishing to judge from the numbers of weirs, is much less intensive (30 to 40 vs. 70 to 100).

The most striking effect on numbers of large herring in the region was shown by the winter fishery, from which they were sold in the frozen condition.

Large herring were well known to concentrate during the summer on the outer limits of the region because they approached the shore and the bottom at the southern end of Grand Manan in enormous numbers in spawning. Spent herring were known to be inside the region in deep water during the winter, but there was little attempt to get them until a market for them in the United States in the frozen condition was developed in the late 1860's. This built up steadily (Figure 2) until by the winter of 1880–81, 32,630,000 fish were taken in the New Brunswick waters of the region and sold in the States (Earll, 1887). These would represent over 10,000,000 pounds of fish. The Canadian records of this fishery are rather unsatisfactory. Vessels from various ports, but mostly local, remained on the ground for long periods in the winter, the fishermen living aboard and setting their nets at night. The fish, when frozen, were sold to buyers from the United States, whose vessels remained largely on their own side of the international border, mainly at Eastport. The statistics of this fishery would be very difficult to collect. Not until the year 1881 were frozen fish as such reported in the statistics, the amount being 16,050,000 fish, which would represent 6,420,000 pounds. They had previously been included with pickled herring which were reported in barrels, and this in spite of the fact that they were nearly always sold by count rather than by the barrel. Doubtless the Canadian statistics of frozen fish from 1881 on were incomplete since they did not include fish taken from the local waters by United States fishermen and by nonresident Canadians. However, the Canadian statistics (Figure 2) provide figures for the fishery after 1881 and they register its further rise to a peak in 1888 and its abrupt collapse after the winter of 1889–90. The fishery itself is well described by Earll (1887), and its passing away by Moore (1898), who investigated the herring fisheries of the region in 1893 and 1895 when the matter was fresh in the minds of those he interviewed.

The Canadian statistics and the reports of officials record on the whole good catches of winter herring in the region up to the winter of 1888–89. At the close of 1889, with a larger catch in the central part of Charlotte County than for some time, Inspector J. H. Pratt at St. Andrews reported that frozen herring showed quite an increase. He wrote: "At the present time our fishermen are putting their gear and vessels in order so as to prosecute winter fishing on the Penfield shore where herrings usually strike about the 1st of January" (Pratt, 1890). The next year he reported that there had been a large decrease in herring of the large kind suitable for export and that different reasons were being given "to account for the decrease of the schools and their lateness in striking our coast". At the close of 1891, he wrote: "The failure of the winter school of large herring to strike into the Bay of Fundy last winter caused large loss to our

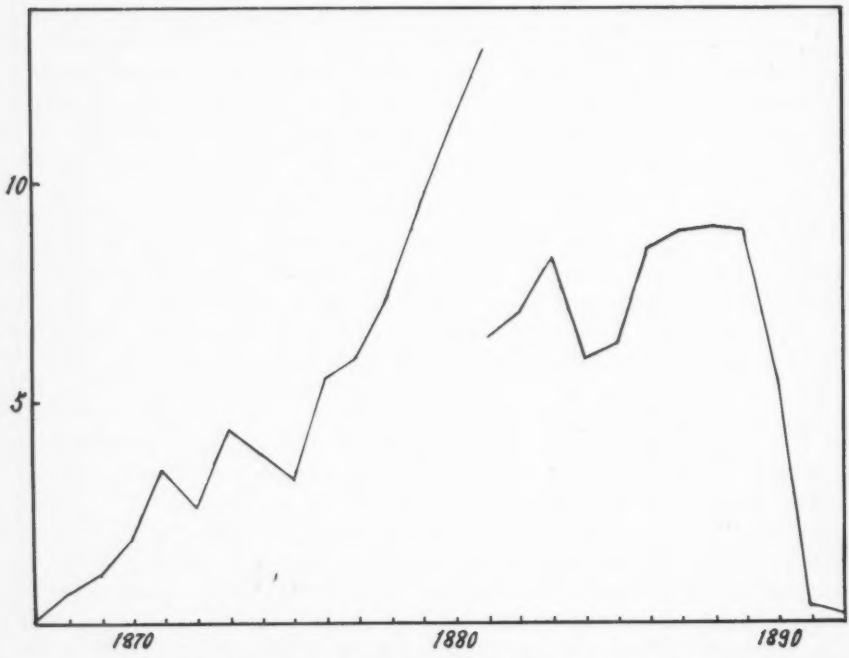

FIGURE 2. Development and collapse of fishery for large spent Quoddy herring taken in winter and frozen for the United States market, in millions of pounds (100 fish = 40 pounds). From 1867 to 1881, as landed in the United States (Earll, 1887). From 1881 to 1892, as reported in Canadian statistics and incomplete.

fishermen. Fishing gear of all kind was placed in proper condition; vessels were overhauled and equipped, trading and fishing crafts were here at anchor with cash ready to purchase the catch, but the long winter passed and not a single school of herring appeared. Various theories have been advanced . . . but the true reason is still enveloped in mystery" (Pratt, 1892). The next year, his report

was that "the usual winter school of large herring for reasons as yet unexplained failed to strike into the Bay of Fundy last winter"; and the following year that "the large herring did not strike into the Bay of Fundy last winter for some reason at present unknown" (Pratt, 1894).

The reasoning that diverted attention from the sardine fishery as a cause of the failure of the winter fishing was well expressed by Overseer D. F. Campbell of St. Andrews: "It is very perplexing to understand, with such large schools of young herring in the bay during the last few years, why there should be so few large herring" (Pratt, 1894). The logic seemed incontrovertible—with so very many quite small herring the spawning stock must still be very numerous. It would never enter anyone's mind that relatively few spawners having very many eggs might actually provide a superabundance of young, which would vitiate the argument used.

That Moore, who described the passing away of the winter fishery for large Quoddy herring, should not have recognized its cause when he was particularly investigating the "alleged decrease" of the local herring through overfishing, is not surprising. The sardine fishery had been well established for a decade when the large herring rather suddenly decreased in numbers, while the length of life of herring was not then known, nor the way in which their growth is affected by spawning. Even now, it is not possible to state how long the Quoddy herring live, since annual checks in growth are very imperfectly recorded on their scales. From the knowledge we have of their growth (Huntsman, 1919), which was merely corroboration of a conclusion reached by a fisherman, Mr. William Flagg of Campobello, long before, as recorded by Perley (1851, p. 111), they reach mature size in three years or so, but grow very little after they have started to spawn. In the regions where they continue to grow at a moderate rate with a rather clear record in the scales, as in certain European waters, they have been found to live for 15 or 20 years, the 1904 year-class forming an important part of the spawning schools for 14 years, that is, till the fish were 17 years old (Hodgson, 1934). It can merely be surmised that a fair proportion of the Quoddy herring may survive for about ten years after starting to spawn in their third or fourth years. That the intense fishery for the young Quoddy herring for canning as sardines, which was well under weigh by 1880, should have resulted in marked reduction in the stock of large herring in about ten years' time, with little recruitment to their numbers and with old age being more or less suddenly added to removal of their numbers by various predators including man, is quite in accord with expectations from what is known of their life-history. Moore stated that "it was impossible to assign any satisfactory cause for their disappearance". He concluded: "it is utterly impossible to believe that these were so preyed upon by the fishermen as to be practically exterminated, so that none were left to return the following year. If they have not been caught out, they must have left the coast in a body". Neither he nor anyone else at the time seems to have considered that these large herring might live for ten years after reaching maturity, and then die of old age, and also might be in such large numbers that the amount taken each year would only slowly reduce the

stock, so that the effect of intensive capture of the young on the rate of recruitment of the adult stock would not appear for quite a number of years.

That there was a very large stock of large herring from which it was comparatively easy at first to get as much as would satisfy the market and the fishermen, and that such satisfaction became increasingly more difficult is apparent from Moore's account (1898). The take of sardines rose rapidly from 1879 to 1886. The course of the winter fishery starting in the late 1870's was as follows: The winter fishery was at first near shore and fishermen did not try farther out when they disappeared inshore. But in 1877 they did try offshore when they disappeared during December and learned that they could get them five or six miles off. They did not have to go offshore the next four winters, "but in 1882–83 they were principally offshore throughout the whole coast, and they did not again appear, to stay, in shallow waters up to the time when they finally disappeared in the winter of 1889–90". The statement that the winter herring disappeared at Grand Manan a year or two earlier appears to have been due to the fishermen there not setting their nets as far from shore, that is, the herring were inshore at Grand Manan until perhaps 1887–88. This would correspond with a reduced stock. Such interpretation is supported by the fact that they first appeared later in the season: "prior to 1880 the winter herring arrived at Herring Cove about November 15, but by 1887 their arrival was delayed until January 6, and in 1888–89, the last year of the fishery they did not come until January 10".

The facts are not that there were no large herring in the region during the winter, but that they were not again to be found in dependably large enough numbers to make the fishery profitable. Moore (1898) stated that "in the winter of 1894–95 for several weeks between December 22 and January 10 the fishing was as good as ever". He raised the question whether the winter herring would return in their former abundance. In the 55 years since then they have not returned, while the intense fishery for the young has continued steadily.

Large herring when still very abundant were taken in very considerable numbers at Grand Manan during the summer, even though the spawning area was closed to fishing. They could be taken more or less readily on the outer side of the island when not congregated on the shore and bottom in spawning. The take of net-herring for pickling dropped rather abruptly after 1888 from a general level representing 4,500,000 pounds to one of less than 2,000,000 pounds (Figure 3), which corroborates the evidence of the winter fishery that the local stock of large herring became considerably less at that time. Moreover, there was a rise of about 50 per cent in the take of the young as sardines from 1898 to 1905, associated with an increase of about 33 per cent in the number of weirs operated. This increase in the intensity of fishing for the young was followed by a drop after 1906 in the quantities of net-herring pickled at Grand Manan to a level representing less than 1,000,000 pounds (Figure 3).

Spawning of large herring of the Quoddy region was almost altogether confined to the limits of the region outside Grand Manan. When they were very abundant, there was a small amount of spawning at the opposite limit of the

region, namely inland in Oak Bay well up on one side of the St. Croix estuary. The winter herring remained in Passamaquoddy Bay until April and these fish spawned in May. It could well be that a small portion of the stock at this inner part of the region in winter failed to go out to Grand Manan, possibly because they were farther advanced toward maturity than the rest, but more probably because they were in Oak Bay and thus away from the river outflow at the surface that would carry them oceanward when they rose from the bottom. They would spawn earlier with the somewhat higher temperatures inland in spring. Moore stated (1898) that reports were uniform that these herring had ceased to spawn except in limited numbers "and as nearly as the date could be fixed from rather vague information, the time of cessation corresponds approximately to the time of disappearance of the winter herring".

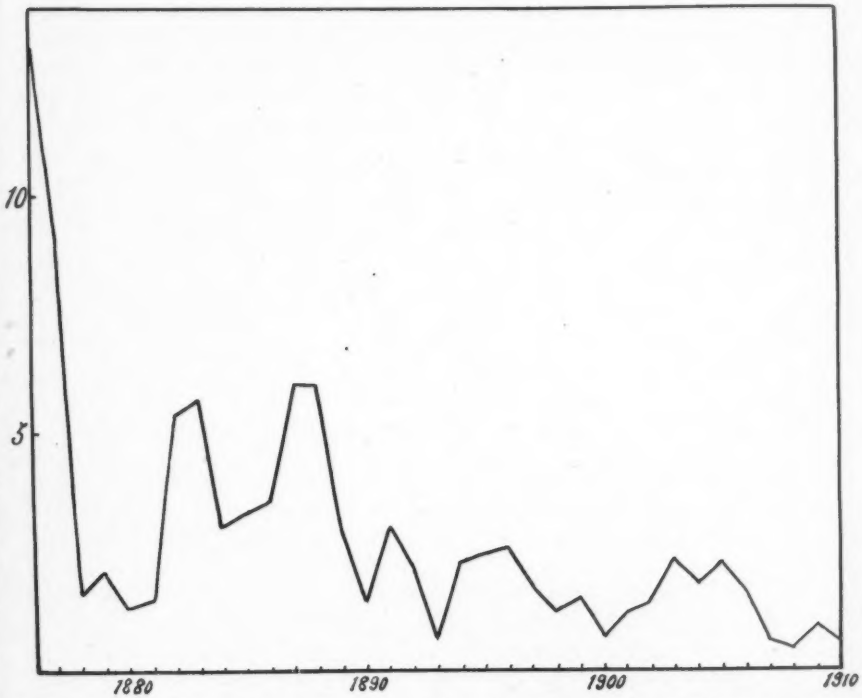

FIGURE 3. Takes of large herring for salting in barrels at Grand Manan from 1876 to 1910.

SUDDEN DISAPPEARANCE OF FAT QUODDY RIVER HERRING

Quoddy River is the name given to the principal passage connecting Passamaquoddy Bay with the Bay of Fundy. In it and in the inlets related to it, such as Harbour de Loutre and Cobscook Bays are to be found the fattest young herring, owing to the presence near the surface of abundant planktonic food

(Battle *et al.*, 1936). In the early days of the fishery this river was almost the exclusive locality for taking the famous "Quoddy herrings", a large fish, which Perley (1851) thought might be the "shad herring", De Kay's *Alosa mattowaca*. He reported that they "are generally without spawn and in the autumn are exceedingly fat and fine flavoured". According to Moore (1898), they were very large and fat, requiring a net mesh of three inches and never contained spawn. They were taken in Quoddy River from August to October, as many as 40 to 50 boats drifting for them almost every night. They rather suddenly disappeared in 1877 and were not again caught until 1892 and then only in limited numbers. They were evidently herring that had grown very rapidly with the abundance of food available and did not go oceanward with the sexually maturing fish, doubtless having a somewhat different behaviour. Their disappearance coincided with the development of the sardine industry at Eastport where the local Cobscook Bay fish, doubtless the precursors of the Quoddy herring, would be used first. The numbers of cans of sardines packed at Eastport in successive years beginning in 1875 were: 60,000; 564,800; 1,209,000; 1,786,000; 1,833,940; 7,550,868 (Earll, 1887).

SEASONAL OR VERY LOCAL MOVEMENTS

In his investigation of the Passamaquoddy herring, Moore (1889) took advantage of the exceptional opportunity they presented to study the behaviour of this species, including its movements, and he provided quite the best account so far published of the factors that determine them. His presentation of the matter was naturally coloured by the prevalent scientific and lay conception that fish migrate for such definite purposes as breeding and feeding. He records the saying of the local fishermen about the herring that "in dry seasons they run into coves and mouths of streams in order to get fresh water to drink", but concludes that "when they do go to such places it is probably to obtain food or escape enemies, and in spite of the fresh water rather than in search of it". That they might not have a purpose was not considered. To illustrate this behaviour: "Guardian Catherine, of Letete . . . states there was a decrease in the catch of sardines in his district caused by the season being extremely dry and the sardine herring went into the heads of the rivers where there were no weirs" (Pratt, 1905).

The behaviour on which the fishermen's saying is apparently based is illustrated by what is definitely reported to occur in Doctor Cove near the southwest corner of Deer Island. This cove dries out at low tide and a weir is built across its mouth so that any herring that enter the cove settle into the heart of the weir at low water. A small brook discharges into the cove on one side. The owner of the weir states that, when herring are in the cove with high water, they collect near the mouth of the brook. The mechanism for this, which I have seen in action for shrimp in a pool with fresh water inflow at Tidal Cove, is as follows: The outflowing fresh water is on the surface and carries outward with it some of the salt water. The latter is replaced by more salt water which flows below the surface inward to the point of discharge of the fresh water. This return current slowly transports any shrimp or fish that may be in it toward the

mouth of the fresh-water stream. This is a simple mechanism for moving fish toward or away from mouths of rivers, depending upon how deep these currents are and upon how far the fish are from the surface. When a mixture of fresh and salt water is itself mixed with more salt water, a triple system of currents is set up of which two, one superficial and one deep, flow toward the mixing place and the third flows from it at an intermediate level. The large amounts of fresh water that are discharged into, and variously mixed by, heavy tidal action with the salt water of the region provide a complex and variable system of currents whose direction varies with depth. The herring themselves, while near the surface, swim at various depths, depending upon their size, the intensity of the light and other things. It might be expected that, like those observed in Doctor Cove, those living in various parts of the region will be shifted more or less from one part to another.

How the small herring or sardines are made available in complex fashion to the weirs around Passamaquoddy Bay by a heavy rainfall which suddenly discharges a very large volume of water into the head of the bay through the Digdeguash River, whose water is not held back by dams for storage, has been clearly shown (Huntsman, 1934). With discharge of large volume, the fish cease to be taken near the point of discharge and then, as it is mixed with the salt water in complex fashion and works out of the bay, large catches of fish are made progressively in a circuit from Letite across to St. Andrews and along the west shore to the head of the bay where the fresh water enters. A most striking and regular thing is that, while all sizes of herring are in deepish water throughout the region during the winter, when they come to the surface in spring with rising temperature they become distributed so that the smallest, brit, are far inland as at the head of Passamaquoddy Bay while the largest, the spawners, are on the outer limits outside Grand Manan.

When large herring were very abundant in the Bay of Fundy, by far the greatest concentration was to be found during the summer outside Grand Manan Island, where they spawned. Mr. W. B. McLaughlin of Seal Cove, Grand Manan, with fifty years' experience, for most of which he was a guardian for the spawning grounds, stated in 1891 (Pratt, 1892) as follows:

> Herring come inshore early in September, seek their birth places and lie on the bottom for rest, not for feeding purposes. Winter gales drive them from Grand Manan to sheltered places near the mainland, where they hibernate on the bottom till spring, returning then to the open sea very poor in quality. While hibernating the herring eats nothing, and if not disturbed will scarcely move till spring.

Disregarding his interpretation, the facts he presents are that the large herring after spawning tend to be inactive and in deepish water without taking much food and that they move inland in the winter and return in the spring still in relatively poor condition. The fishery for the large herring in winter showed clearly their movement into or through the region, its extent and also its variability.

Earll (1887) from investigations made in 1881 at the height of the industry in frozen winter herring describes the movement inwards as follows:

The fish arrive off the southern head of Grand Manan during the month of July, where they remain until the middle of September. Late in October other schools gradually approach the shore of the mainland, in the vicinity of Campobello Island, just opposite Eastport; as the season advances the numbers increase, until, in midwinter, the waters between Eastport and LePreau are literally filled with herring, great numbers of them entering and remaining in Saint Andrews Bay until late in the spring.

. . . . During the first of the season the bulk of the herring are usually taken in the vicinity of Deer Island and Campobello, later they are more abundant about Beaver Harbour and Point LePreau, while in the spring the fishing is often extensive in Saint Andrews Bay. This rule is not constant, however, as the fisheries of the different localities vary greatly from time to time, one particular section being much less important in one season than another.

Moore (1898), who investigated the fishery after it had failed for many years, describes the movements thus:

The winter run of herring did not strike the whole coast at once; they usually first appeared on the outer or Bay of Fundy side of Campobello and thence extended eastward and to a limited extent westward. A school of fish usually arrived on the shore at Herring Cove early in October, and remained about three or four weeks. This school appeared to be distinct from the true winter herring, which, before 1880, reached the place mentioned with fair regularity about November 15, and remained until late in December, when they began to slack off, although some were usually to be found there throughout the winter. The fishermen from Beaver Harbor came down to Campobello for a fortnight's fishing early in the season, as the schools did not strike Beaver Harbor for about ten days after their arrival at Herring Cove, and it would not be until about the first week in December that they would reach the neighborhood of Point Lepreau.

It would appear, then, that these schools of winter herring arrived first at Grand Manan, soon afterwards at Campobello, and thence they extended gradually up the Bay of Fundy to St. John, or entered St. Andrews Bay via Head Harbor and the Eastern or Letite Passage. At the eastern end of Campobello, at Head Harbor, the migrating schools had two alternatives, they could either continue up the Bay of Fundy or could enter St. Andrews Bay. When they took the latter course in large numbers there was a corresponding dearth upon the Bay of Fundy shore, but sometimes the schools would divide, a portion taking each route and the fishery becoming more widely distributed.

The foregoing is a general statement and does not strictly describe the migration every season. Sometimes they were first caught nearer the eastern end of Campobello, and there were always more or less extensive local movements which tended to affect their distribution. They often moved about from place to place according to no observable system, but the fishermen were able to follow them with more or less certainty by observing the movements of the schools of whales and flocks of gulls. For instance, in 1877 there was good inshore fishing at Campobello up to the middle or latter part of December, but during the rest of the winter they were offshore, and it was during that winter that the fishermen gained their first experience in deep-water fishing, at some expense of nets and gear. West of Beaver Harbor the principal schools were that year found about midway between the main shore and The Wolves, but farter eastward, at Popologan and Lepreau, they were closer inshore.

The extent of the movements was (1) oceanward, some distance outside Grand Manan and (2) inland as far as Oak Bay on the St. Croix River and the mouth of the estuary of the Saint John River. Oak Bay was a usual inland limit, but the Saint John estuary an unusual one. Overseer Joseph O'Brien reported for 1881 that "the schools came quite into the harbour, which is a most unusual occurrence, as they seldom come inside Partridge Island, and then remain only for a short time. But this season they remained in the harbour four or five weeks". Also, from 1878 to 1883, barrels of herring were reported as taken every year from Kennebecasis Bay inside the mouth of the estuary in Kings County, and these doubtless entered during the winter as hake rather regularly do. The

most invariable inland distribution in quantity was along the Pennfield shore, that is, somewhat midway between the St. Croix River with Passamaquoddy Bay and the Saint John estuary.

The difference between winter and summer in the distribution of these large herring is a striking one (Figure 4). In the summer, they were outside Grand Manan and moved against its southern shore in late summer at spawning time. In the winter, they were largely along the mainland coast to the north, between the northern end of Campobello Island and Point Lepreau, and some went inside Passamaquoddy Bay. It is noteworthy that in winter some failed to leave Grand Manan, being pocketed inside Long Island, away from the action of currents. Similarly, some of the herring in Passamaquoddy Bay in winter failed to move back to Grand Manan, but were pocketed in Oak Bay far inland and away from the action of the currents in the outflows from the St. Croix and Waweig Rivers. Here they spawned in spring.

The fresh water discharged into the region comes mainly from the Saint John River, and next from the St. Croix River, with the adjacent Digdeguash and Magaguadavic Rivers, all emptying into Passamaquoddy Bay. Between are the smaller rivers, Pocologan, New and Lepreau emptying into Mace Bay west of Point Lepreau and the Musquash into the coast halfway between that Point and Saint John. Discharges from all of these are mixed with the salt water at various stages in their progress oceanward. Their final mixing before spreading out over the surface of the deep open Gulf of Maine or moving westward along the broken coast of Maine for further mixing, occurs among the islands and over the shoals and ledges that stretch for about 10 miles out from Grand Manan Island. To this mixing area with its strong tides the mixtures of fresh and salt water flow. Here is clearly the outer summer distribution of the large Quoddy herring, that move against the southern end of Grand Manan in the late summer in spawning and that move inward toward river mouths in fall and winter.

The complex hydrographic conditions in the region have been studied by Hachey (1934a, 1934b, 1935, 1939) and Watson (1931, 1936). The general picture is quite clear, while the details vary so much that the actual circulation of the water during any period needs to be determined rather than calculated. The circulation is quite slow in comparison with the tidal currents. For example, a heavy rainfall discharged mainly through the Digdeguash River into the head of Passamaquoddy Bay has been found to take more than a week to work out through the main mouth of the bay a distance of some 20 miles. As reported, the herring shifted from Herring Cove, Campobello, to Beaver Harbour, a distance of about 15 miles in 10 days, and in about another week they reached Point Lepreau, a further distance of about 10 miles. It is not to be expected that they would be shifted by the deeper circulation as rapidly as the most rapid circulation near the surface. The rate of their movements is of the right order to result from their being shifted by the water circulation. Their movement from outside Grand Manan in fall and winter toward the river mouths may be safely ascribed to the somewhat deep return current of salt water that replaces the salt water that goes oceanward in the mixture with river water at

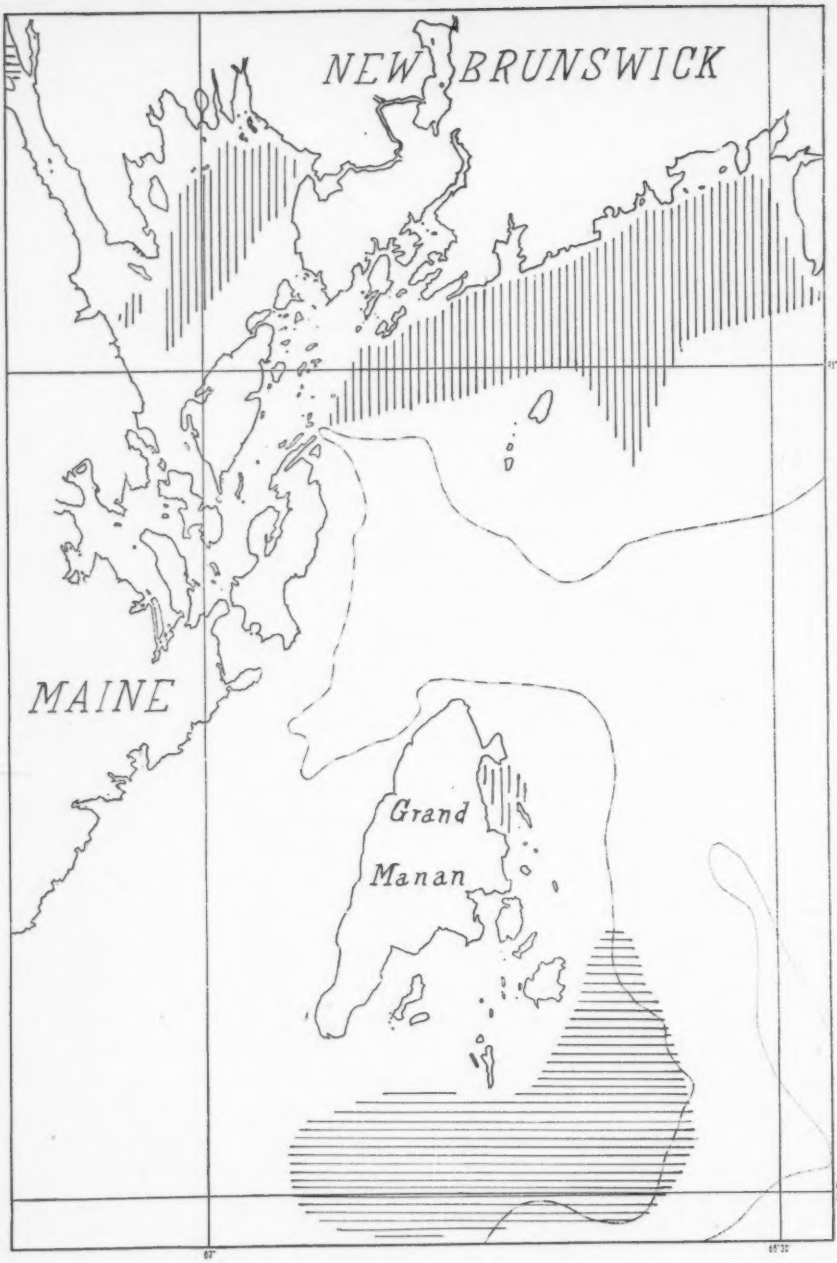

FIGURE 4. West part of the mouth of the Bay of Fundy, showing the summer (horizontal ruling) and winter (vertical ruling) distributions of the large herring when abundant in the 19th century. Locations of the winter schools are as reported to A. E. Calder by Wheeler Mallock and J. W. Matthews, who had fished them.

the surface. The movement in the reverse direction in the spring may be considerably more rapid since it is probably near the surface. At that time the fish will be quite active and feeding with rising temperature. Therefore, the schools will not be dense, and may be broken up, since the fish tend to separate in feeding. Under such conditions they would not be caught in large quantities in gill-nets. There are no reports of this oceanward movement being observed.

The extent of the movement riverward in fall and winter varied considerably from year to year, doubtless in accordance with variations in fresh-water discharge. The published data of the quantities marketed are not very useful for comparing the extent of the movement in different years. Beginning in 1876, the amounts were reported separately for the districts of Grand Manan, Campobello, Deer Island, Passamaquoddy Bay, St. Croix, Letite to Lepreau, and Lepreau to Saint John. However, the products of the winter fishery were not reported separately, nor did the fishermen keep to their own districts. The reports of the overseers can be relied upon for any pronounced conditions. For 1881, the fish were well inland: Overseer O'Brien of Saint John stated that "the catch of herring was much larger than last year, and the schools came quite into the harbour, which is a most unusual occurrence". Overseer Cunningham of St. Andrews stated that there was "a large catch of herring last winter, the quality of which was excellent". For 1884, the fish went little inland. Overseer O'Brien stated that "our fishermen were much disappointed in the small catch of herring during the winter . . . from some unknown cause the schools did not come in as formerly". Overseer Cunningham said that "herring did not come into the Bay last winter in any considerable numbers, and the fleet of vessels which usually fish here was obliged to seek fares in other waters". Overseer Lord of Deer Island stated that "the quality of frozen herring packed was much short of last year's catch; the fish did not as usual, come to our shores, and nearly the whole catch was made in Grand Manan". Overseer McLaughlin of Grand Manan stated that "the shipment of frozen herring has been immense".

LARGE-SCALE MOVEMENT TOWARD SAINT JOHN

A most pronounced shifting of a large part of the stock from Grand Manan along the axis of the Saint John outflow resulted in much of the stock being lost to the Quoddy region by going to the Bay of Fundy eastward and northward of the region. The upper part of the bay has a very different type of circulation, one that is horizontal rather than vertical. Little fresh water enters directly into this part. The water of somewhat low salinity and high summer temperature from Minas and Cumberland Basins enters into the head of the bay and passes oceanward along the New Brunswick shore, while water of somewhat high salinity and low summer temperature passes to the head of the bay from the Gulf of Maine along the Nova Scotian shore. Between these two streams, there is a slow interchange of water across the bay, the movement being toward Nova Scotia near the surface and toward New Brunswick near the bottom. In this way the streams change in character as they proceed. Into this circulation went a large body of Quoddy herring, beginning in 1877.

For that year, Overseer McLaughlin of Grand Manan reported that "net fishing for herring was exceptionally good the first six months of the year, since which there has been a gradual falling off in quantity, with an extraordinary leanness in quality". That is, when the fish were expected to become more abundant in approaching the shore at spawning time starting in July, they became less abundant. The leanness in quality would mean that they were short of food which is brought to them by indraft from the Gulf of Maine in the return current from outflow of fresh water. This indicates that the fresh-water outflow through the region had been considerably reduced. The direction in which the fish were being moved was shown by there being a decrease in the catch of herring in Passamaquoddy Bay (Cunningham), and a very large catch between Letite and Lepreau (Best), and also by Overseer O'Brien reporting for the Saint John outflow that "the herring in the bay the past year has been the best ever known". They were going toward Saint John. The Grand Manan catch was markedly low for the next four years and Overseer McLaughlin, who felt responsible for the

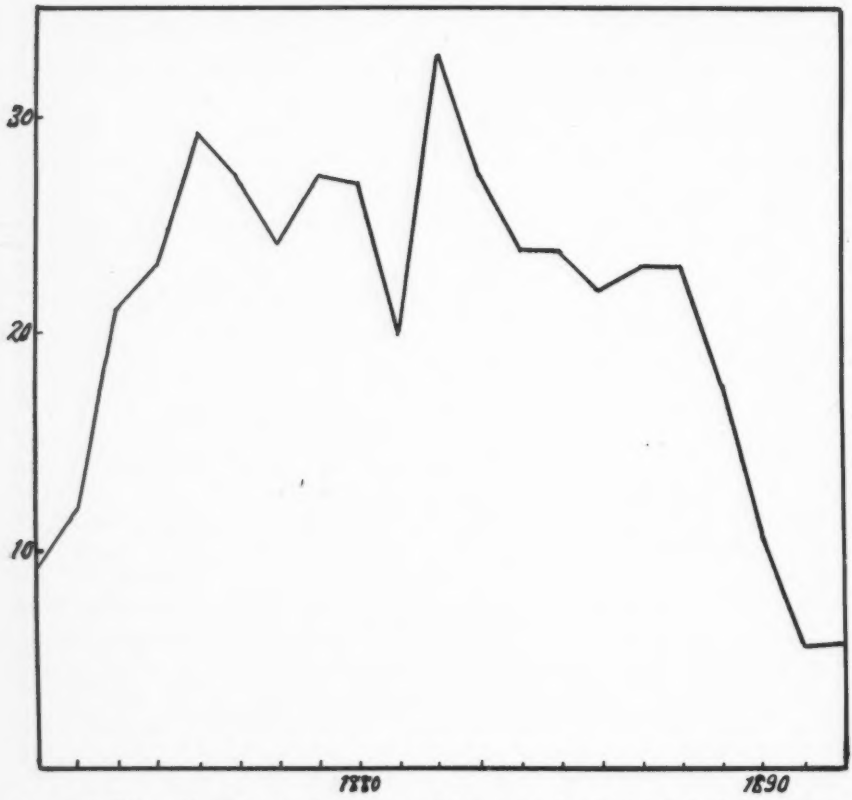

FIGURE 5. Takes of large herring for salting and freezing in Charlotte and St. John Counties, N. B., from 1872 to 1892.

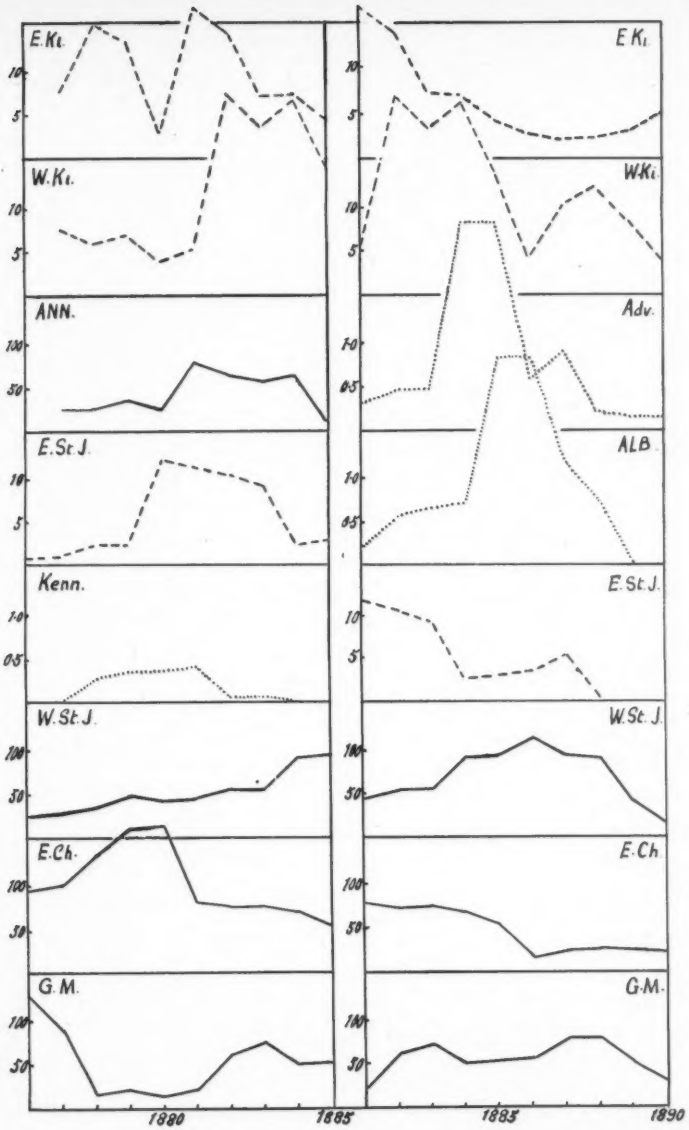

FIGURE 6. Large herring landed on shores of the Bay of Fundy from 1876 to 1890, showing on left from 1876 to 1885 movement going from Grand Manan to Minas Channel, and on right from 1881 to 1885 movement returning from Minas Channel to West St. John County and possibly Grand Manan. Amounts in hundred thousands of pounds on three scales (———— = 10 × – – – – – = 100 × · · · · · ·). On left, districts from below upwards are: Grand Manan; east Charlotte County; west St. John County; Kings County, N. B. (Kennebecasis); east St. John County (Quaco); Annapolis County, N. S.; west Kings County, N. S. (Black Point to Morden); east Kings County (Scott Bay to Halls Harbour). On right, districts from above downwards are: East Kings County, N. S.; west Kings County; Advocate (Cumberland County); Albert County, N. B.; east St. John County (Quaco); west St. John County; east Charlotte County; Grand Manan.

stock because he was guardian of the main spawning area at Grand Manan, explained the situation as probably the result of migrations to northern Europe. Nowhere else did he see a sufficient increase in the catch to account for the very large quantity that failed to be found at Grand Manan. That the fish had not really gone very far is shown by the fact that the take of large herring in Charlotte and St. John Counties showed (Figure 5) no great diminution at this time. There was somewhat of a drop for four years, which was most pronounced in 1881, after which it was higher than ever.

For a period of about five years there was failure in the usual shifting of the immense mass of large Quoddy herring between inland in winter and oceanward in summer. It was the latter that largely failed. These fish continued to be available to the customary extent in the inland waters of Charlotte County as shown by the local reports both verbal and statistical. At the same time there was a change in the distribution along the coast initiated in the winter of 1876–77 as stated above, more of the fish going toward Saint John, and being taken in eastern Charlotte County and western St. John County (Figure 6 and Table V). In the previous winter the fish had been few in Passamaquoddy Bay and plentiful enough, although far from shore. "Our fishermen who own vessels have now to go a distance of six to eight miles off shore before they can catch any" (Cunningham). "The winter fishery was principally done in deep water as

TABLE V. Pickled, fresh and frozen herring in hundredweights as landed for districts along northwest shore of Bay of Fundy from Grand Manan to Advocate.

	1876	1877	1878	1879	1880	1881	1882	1883
Grand Manan	132,000	90,000	16,500	21,000	13,500	22,000	62,000	77,000
Eastern Charlotte	94,200	110,850	139,200	167,400	168,000	80,000	74,000	77,000
Western Saint John	25,500	30,000	34,200	48,600	42,000	46,600	56,000	56,800
Kings (Kennebecasis)	0	0	270	330	336	390	36	45
Eastern Saint John	900	1,080	2,340	2,400	12,450	11,700	10,500	9,000
Albert	450	360	270	285	315	210	555	675
Advocate	900	1,050	750	600	750	300	450	480

	1884	1885	1886	1887	1888	1889	1890	1891
Grand Manan	50,000	53,000	56,000	80,000	80,022	50,000	29,000	34,000
Eastern Charlotte	69,000	54,000	15,500	24,900	28,500	27,400	27,200	6,108
Western Saint John	91,000	95,000	114,000	93,000	90,400	41,000	18,500	6,000
Kings (Kennebecasis)	0	0	0	0	0	0	0	0
Eastern Saint John	2,700	3,000	3,600	5,400	375	?	?	105
Albert	711	2,400	2,400	1,200	75	0	0	105
Advocate	2,400	2,400	600	900	210	150	150	195

rough weather prevailed most of the time, the fishermen found it very difficult to take care of their nets, a great many of which were lost. A large number of American vessels now frequent our coasts to engage in the fishery" (Best). Before the failure of much of the stock to appear at Grand Manan in the summer, there was a shifting of it in winter offshore and eastward. From 1877 on, however, the western part of the stock did go well inland in winter. The only peculiarity in the west, which coincided with high quantities near Saint John and low quantities at Grand Manan for a number of years starting in 1877, was the failure of fat Quoddy herring.

The large part of the stock that was at first shifted eastward in the winters of 1875–76 and 1876–77 into the axis of the Saint John outflow was naturally then shifted northward in the return current of that outflow toward Saint John. It would appear that such movement was not particularly reversible. There is no indication that they remained in the Saint John outflow till spawning time, but at times at least they remained on into the summer. For 1884, Overseer O'Brien states: "The catch during the summer, however, was almost without precedent, in many instances nets being literally carried away by the numbers of fish striking them". They clearly failed more or less to return to Grand Manan from this district.

The relation of the Saint John outflow to the failure of a large part of the stock to return in spring and summer to Grand Manan for the four years starting in 1878 is clearly shown by the reports of catching of herring for Kings County in the Kennebecasis, a deep side-bay off the Saint John River into which hake normally pass in the winter. In each of those four years, about 100 barrels were reported, but none in previous years (Figure 6 and Table V). A dozen or so were reported in the two following years, but none thereafter. Overseer Samuel Gosline makes no comment on this unusual occurrence, but for 1881 when the greatest amount of herring was reported he states for the Kennebecasis: "Winter hake fishing through the ice continues to increase, and considerable numbers are taken for home use". Amounts of dried hake in cwt. for 1876 and the successive six years were 0; 75; 90; 150; 171; 174; 60. It seems evident that from 1877 to 1881 unusual quantities of herring and hake were carried in during the winter through the Reversing Falls. That is, starting with the winter of 1876–77, at least for hake, there was unusual inward movement, in agreement with the behaviour of herring to the westward.

MOVEMENT OUT INTO THE OPEN PART OF THE BAY OF FUNDY

The quantities taken near and inside Saint John in those years were altogether too small to account for the large loss of stock from Grand Manan. The only direction for the fish so shifted to go was farther eastward out of the Saint John outflow and into the circulation of the remainder of the Bay of Fundy. That they did go in that direction is clearly shown by the catches made there. The most remarkable change was along the New Brunswick shore eastward from Saint John as far at least as Quaco, a distance of 25 miles. This is quite a straight coast, poorly provided with shelter for boats and vessels. Never-

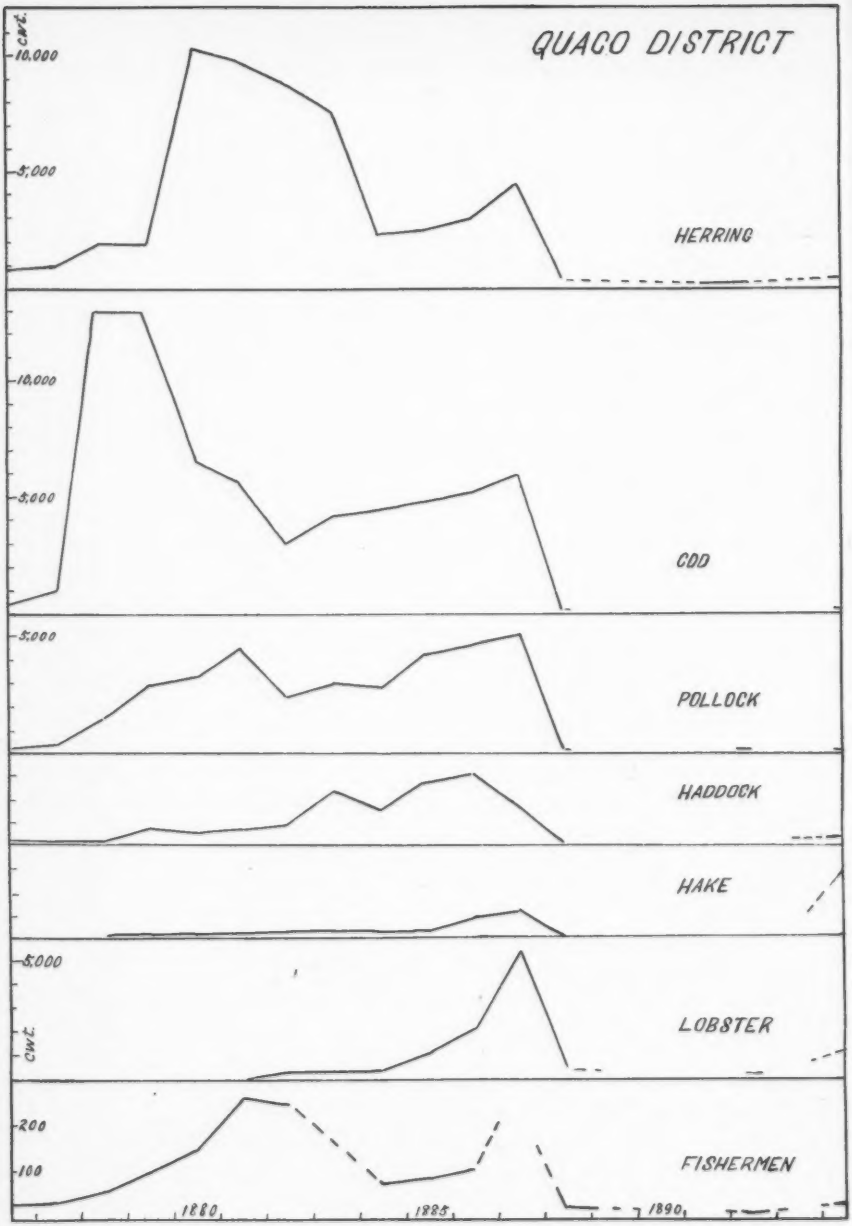

FIGURE 7. Quantities of fish of various kinds in hundredweights that were taken each year in the Quaco district (eastern St. John County, N.B.) from 1876 to 1894, and also the number of fishermen, as given in the Annual Reports of the Commissioner or Department of Fisheries of Canada.

theless there were apt to be fairly considerable bodies of fish, particularly in relation to the shoal area off Quaco Head, and 10 miles or so out at Quaco Ledge. These were sufficient to attract outside fishermen, Overseer William Skillen of St. Martins reporting for 1877 that it was impossible for him to get full returns because a large number of small vessels that resorted there to fish never came to shore, but having made their fares, left for home or a market. Herring occur along this coast during summer and spawn eastward of Cape Spencer (Perley, 1851), that is, just beyond the influence of the Saint John outflow.

The striking course that this local fishery (eastern St. John County) took (Figures 6 and 7 and Table V) is revealed by the reports of Overseer Skillen, who was appointed in 1873. In 1874, men had been drawn away from it with high wages in the shipyards, but it improved in 1875. It dropped off in 1876, with the fish arriving late and leaving early, but the catches were on the whole somewhat better in 1877. Then in 1878, the year following the beginning of a movement of a large part of the Quoddy stock of herring away from Grand Manan toward the east and north, he reported a great improvement. His figures show the herring and haddock catches doubling, the pollock catch quadrupling and the cod catch 25 times as great as in the previous year. Only the halibut showed little change. A small amount of hake was reported for the first time. Considering that the herring were brought by the circulation, it would be a question whether the other fishes were similarly brought, or whether as predators on herring any reaching a place with large masses of herring would remain. For 1879, Overseer Skillen reported:

> You will notice by my returns that a very much larger number of vessels and men are employed in my district this year than formerly. This increase is not entirely from our own people, but partially from Campo Bello, Deer Island, and St. Andrews. The vessels from these places make Ten Mile Creek their head quarters, and from this place quite a number of Gloucester fishermen were supplied with bait, for which they paid one dollar a barrel. The catch this season has been very good and profitable, even at the low prices ruling.

His figures show that the pollock catch was doubled, the haddock catch more than quadrupled (haddock feed on herring spawn and are caught on the spawning beds), and small amounts of shad and mackerel were recorded for the first time.

For 1880, Overseer Skillen reported a large increase in the catch of herring but a falling off in line-fish. His figures show the herring catch quintupled, the halibut catch up 50 per cent, the mackerel and hake greatly increased but quantities still small, while the cod catch had dropped a half and the haddock catch a third. It would seem that a mass of herring had moved in closer to the coast, with a varied effect. The Overseer proposed that, as had long been done at Grand Manan, the herring spawning ground in his district should be protected from fishing from July 10 to August 20.

For 1881, he reported that the catch was "considerably over that of last year", but his figures show little difference, with pollock and hake increasing somewhat and haddock greatly reduced. He again pressed for protection of the herring spawning grounds. He reported for 1882:

Line fishing on the whole was not so good, and fewer men were engaged in it than in former years. Some of them engaged in lobster fishing as an experiment, and the result shows that this shellfish is plentiful from Mispeck to Roger's Head, the size and quality good. The greatest catch of herrings made in this district was when the fish came in to spawn. It is a pity that all the well known spawning places of herring are not protected . . . Codfish and halibut are generally plentiful around Quaco Ledges, but owing to rough weather and prevailing fogs last season, vessels could not pursue these fisheries to advantage.

However, his figures show little change from the previous year, except that cod and pollock were down nearly a half and a few lobsters are recorded. For 1883, his report was:

The catch, though slightly better than last year, is not in proportion to the means employed. Fish were very late in striking our shores, and the whole work of the season was done in a very short time . . . During the present season, I carefully examined the herring spawning ground, between Roger's Head and Ten Mile Creek, on which I formerly reported. This year it was nearly the end of July before the school came to spawn. They nearly all struck the shore below the creek, and immense hauls were made while they remained . . . I would again urge that the great destruction of gravid herrings, which has heretofore been committed on this spawning ground, be prevented in future.

His figures show little change. A slight decrease in the herring catch, coupled with their late arrival may be interpreted as showing that the large mass was beginning to move away from the coast.

For 1884, he reported "The catch of herring is below the average; other kinds of fish about the same as last year . . . Pollock were plentiful, but were not fished for with much vigor—low prices the cause. I fixed the limits of spawning ground under Order in Council of 29th May, between Split Rock and Roger's Head, and had very little difficulty in protecting these limits. What the difficulty may be when the usual fleet of vessels visit these waters in spawning time, remains to be seen". His figures show little change, except that the herring catch had dropped to less than a third. He now had power to stop the best of the herring fishing.

For 1885, he reported "an increased aggregate catch, although herring fishing was considerably reduced in consequence of some of the best fishing places being reserved as spawning grounds", and he had some difficulty in protecting the spawning limits. His figures show as many herring caught as in the previous year, but under the circumstances his knowledge of what were caught would be questionable when he was in conflict with the fishermen. For 1886, he reported similarly, and his figures showed considerable increases in haddock, lobsters, shad, mackerel and hake, but marked decreases in pollock and halibut.

It would seem that his policy of protecting the spawning grounds met with too much opposition. In 1887, he was replaced by Overseer E. V. Rourke, who merely reported "an average catch of fish", with figures showing a 50 per cent increase in herring (without protection?), and very considerable increases in pollock and halibut.

Whatever may have been the reason and whatever had been the real state of affairs in 1887 to bring about a change in officers, the fishery had definitely collapsed in 1888 (Figure 7). The new Overseer merely reported "average catches of herring and lobsters, which are the only fishes the capture of which

is pursued with any energy in this district. Line-fishing for pollock and cod is not followed to the same extent as formerly; but a small quantity of each was taken for home use". One is tempted to surmise that a moving-away of the main mass of herring reversed what had happened in 1878, and that an officer who had persuaded the Government to protect the large numbers of spawning fish lost credit when there very few fish to protect and the local fishery was clearly failing. The figures given for 1888 show relatively negligible quantities of herring, cod, lobsters, pollock and haddock and nothing else.

For 1889, the catches were not reported separately, but Overseer Rourke reported "the catch of herring as small—far below that of last season. The lobster catch is a mere cipher, only one man being engaged in this branch of the fishery for a short time", and for 1890 "the catch small, the fishery not being prosecuted as in former years. There were but very few herrings on this shore at any time during the past season". For 1891, there was no verbal report published, but separate figures showed small quantities of herring, cod, lobsters, pollock, haddock and halibut being taken. For 1892, the quantities were similar and there was the statement: "The natives there have lost all interest in fishing". It was evidently considered that, under such conditions, an Overseer was not needed, since there was no report in 1893 and no Overseer listed in 1894. A Guardian reported in 1895 and then there were no reports until Skillen came back as a Guardian in 1901.

The herring from Grand Manan had come to Quaco and given relatively wonderful fishing, and when they gave out either by moving away or becoming exhausted through old age without recruitment, the drop back to the previous low condition of the fishery was such an anticlimax as to be depressing (Figure 7). However, by 1894 a moderately good fishery was re-established, with quantities similar to those taken in 1876 and with the addition of lobsters and hake which were discovered to be present in fair quantities when the fishermen that went there for cod, haddock and pollock found these expected kinds to be lacking.

If the striking increase in herring at Quaco was due to fish coming from elsewhere and if they came from Grand Manan as the timing suggests, there is the question as to the course they took to reach Quaco. There is nothing to suggest that they went along the coast from Saint John, and the circulation of the water is against such movement. If some of the herring in the Saint John outflow passed from it eastward into the bay, they would be apt to be carried in the contraclockwise circulation around the bay, (as well as going to or from places where fresher water is being mixed with sea water) *to* such a place when well down in the water and *from* it when well up. The entire inner part of the bay is sufficiently shallow, considering the strength of the tides, to have the water at any place quite thoroughly mixed from top to bottom (Watson, 1936). Under these conditions, movements oceanward from the mixing places extends well down from the surface, and the deeper the water the farther down is the oceanward movement. As they live near the surface, the herring will be carried toward the salter water when over deep water, and toward mixing places when in shallow water. As the salter water is along the Nova Scotian shore and

moving up the bay, herring from the offing of Saint John will be carried in a contraclockwise circuit around the bay. Also, when up in the water in summer, their movement will be towards the mouth of the bay and the Nova Scotian shore, and when down in the water in winter, toward the head of the bay and the New Brunswick shore. A circuit from that offing would be rather far from shore, and in it the fish would be drawn to shore first where shallows jut farthest out. The shoal ground off Quaco is the only one jutting out in this circuit. This serves to explain the rather prompt appearance at Quaco of part of the mass of herring that left Grand Manan, starting in 1876, in spite of the rather strong movement of water from Quaco outward past Grand Manan. From Quaco the fish were distributed along the course of this movement as far as Roger's Head. There is no mention of their being northeastward from Quaco toward Salmon River, which would have no such explanation.

MOVEMENT TO NOVA SCOTIA AND AROUND INNER BAY OF FUNDY

To judge from the Quoddy region, movement of large herring toward fresher mixing places occurs in winter, which would restrict the summer fishery at Quaco to winter arrivals. The whole fishery of the inner Bay of Fundy is during the summer, and it is then that the herring are most active and nearest the surface, which would permit them to be most easily carried. The summer is the season when high inland temperature is added to fresher inland water to make a stronger surface movement out of the bay and toward the Nova Scotian coast where the salter ocean water moves toward the head of the bay to be consumed by mixture with fresher water. Surface objects such as drift bottles (Figure 8) go ashore along the Nova Scotian coast as far as Minas Channel. Its narrowness and tortuosity prevent horizontal separation of inflowing salter water and outflowing fresher water. The outflow is at the surface all the way across and tends to stop further inward movement of surface forms or material. In the mouth of the channel is the famous "cedar swamp" of drift material of varied origin.

Compared with Quaco, any addition to the stock of large herring on the Annapolis-Kings shore would have to be very considerable to be noticeable. From about five to about seven millions of pounds were being taken annually on the shore when the large mass left Grand Manan. If the slight rise in quantity at Quaco in 1878 represented the presence of some of the mass in the inner Bay, it made no evident rise on the Annapolis shore until 1879 (Table VI) when a 50 per cent rise in catch was reported. However, most of the gain was lost in 1880. In 1881, there was no question, since the catch rose from three to over eight million pounds for Annapolis. That was the year when there was a very abrupt drop in East Charlotte and the beginning of the decline at Quaco. At each place on the Nova Scotian shore, just as for Quaco, the high level was maintained for four years and followed by a very abrupt drop (Table VI).

That a mass of herring should take a year for both van and rear to cross the Bay, which is about 30 miles wide, means very slow movement even with a circular course being followed. With such circulation as exists in relation to

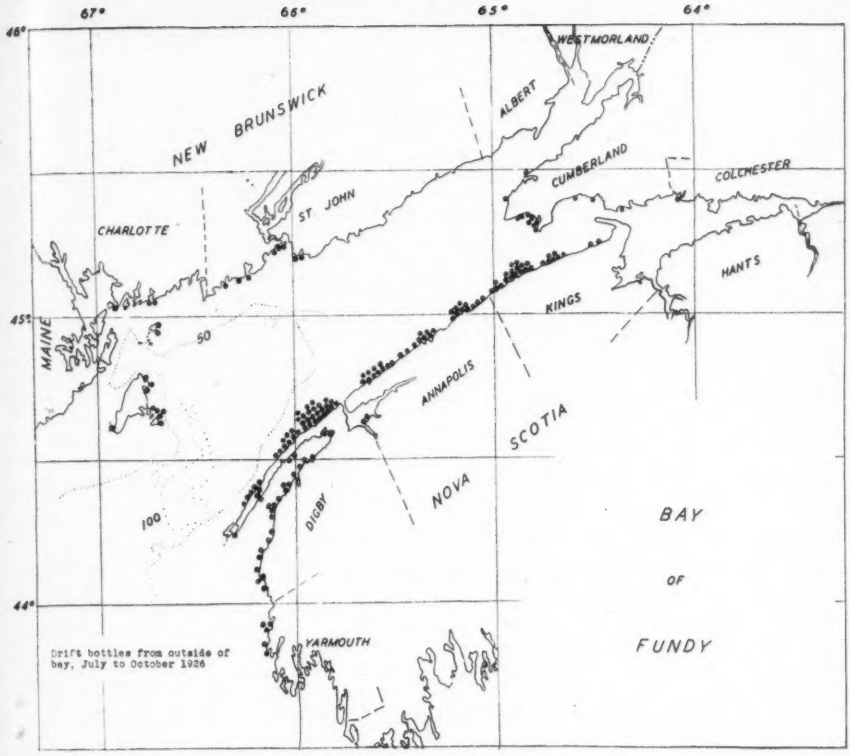

FIGURE 8. Landings of drift bottles on shores of Bay of Fundy when carried inward from Cape Sable in experiments of 1926.

TABLE VI. Herring in hundredweights landed along the Fundy shore of Kings and Annapolis Counties, Nova Scotia.

	1877	1878	1879	1880	1881	1882	1883
Scott Bay to Hall's Harbour	7,900	15,600	13,320	3,050	17,394	14,364	7,640
Black Rock to Morden	7,635	5,790	6,960	3,870	5,200	*23,125*	*19,230*
Margaretville and Pt. George	7,230	6,760	7,645	6,780	*10,400*	*11,590*	*21,300*
Port Lorne to Hampton	10,500	10,500	14,850	8,400	*30,300*	*12,608*	*10,410*
Phinney Cove to Lash Cove	7,800	7,530	12,240	10,260	*38,400*	*38,537*	*26,490*
	1884	1885	1886	1887	1888	1889	1890
Scott Bay to Hall's Harbour	7,221	4,285	2,875	2,187	2,335	3,175	5,326
Black Rock to Morden	*22,306*	*14,180*	4,280	10,240	12,705	8,530	4,693
Margaretville and Pt. George	*18,800*	5,300	1,350	5,631	3,000	3,382	552
Port Lorne to Hampton	*12,000*	900	2,355	2,400	1,500	2,100	300
Phinney Cove to Lash Cove	*34,500*	3,006	3,066	5,115	6,573	4,521	1,026

mixing of light and heavy water, whether the fish are carried in one direction or the reverse depends upon their level in the water, which varies throughout the day as well as throughout the year. Since in the Quoddy region the winter and summer shiftings tend to cancel each other, slow movement of the mass across or around the bay may be the result of to-and-fro movement, as between night and day and as between winter and summer, in transport by the slow circulation of the water. The depth of the water doubtless enters into the matter. The depths involved are even more than 50 fathoms, depending upon the course taken in crossing the bay, since the water deepens going outward from a maximum of 40 fathoms opposite Quaco, of 52 fathoms opposite Saint John and 70 fathoms opposite Point Lepreau.

On the Nova Scotian shore the mass moved inward nearly to Minas Channel, not clearly reaching Hall's Harbour in the mouth (Figure 9 and Table VI) where there were high catches before 1880. Its effect was most pronounced near Digby Gut at the outer end of this shore. At the farthest point it reached inward, Morden to Black Rock, it showed only a year later than near Digby Gut. At the latter place it was in full force the first year, but farther in near Margaretsville it built up slowly.

Whither went the mass when leaving the Nova Scotian shore? For Annapolis County the drop in catch after the four years of abundance was catastrophic. For 1885, Overseer W. F. Carty reported: "Last year, the coast of the Bay of Fundy seemed to be swarming with herring, and so many were taken that the fishermen hardly knew what to do with them; while this season, although every lawful method has been followed, comparatively nothing has been taken, very few of the fishermen having caught sufficient to entitle them to the bounty". There is evidence that the van of the mass had already completed the circuit of the bay by reaching the Saint John outflow. The catch of herring in that outflow (West Saint John County, Saint John to Lepreau) had remained steady at quite a high level after going up from 1876 to 1879 with the movement of herring from Grand Manan toward the Saint John estuary (Figure 6). Then for 1884 Overseer O'Brien reported "Our fishermen were much disappointed at the small catch of herring during the winter. For two previous winters fish were very plentiful, and good prǫfits were realized from the large catches made; but from some unknown cause the schools did not come in as formerly. The catch during the summer, however, was almost without precedent—in many instances nets being literally carried away by the numbers of fish striking them". This sudden appearance in the summer could seemingly have come only from the northeast, that is, from the direction where the herring were on the Kings County shore. There they appeared in 1882. The circulation would take them thence to the offing of the Saint John outflow, following the contour lines south of Isle Haute and Quaco Ledge. That such movement should take two years would accord with the shallower water (25 to 30 fathoms) compared with the crossing to Nova Scotia in one year with deeper water toward the mouth of the Bay. That the mass passed Quaco is to be inferred by the fact that the catch there built up somewhat from 1884 to 1887 (Table V). The collapse of the

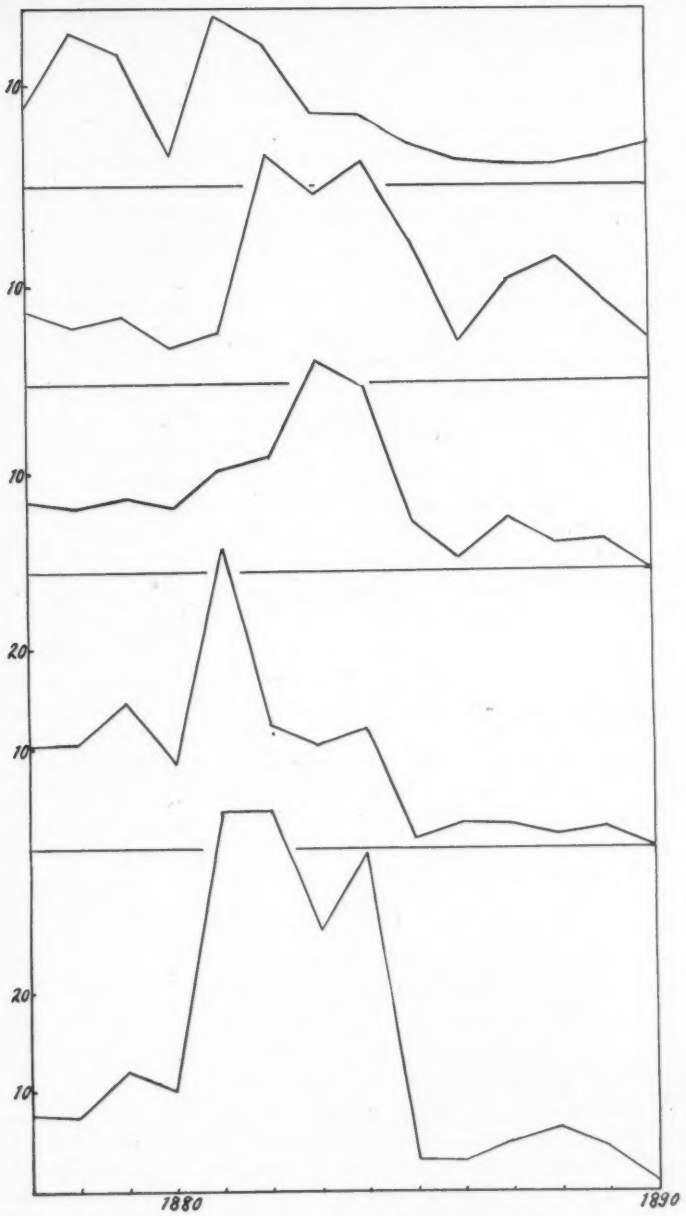

FIGURE 9. Large herring landed on Nova Scotian shore of the Bay of Fundy from Minas Channel to Digby Gut from 1877 to 1890 in hundred thousands of pounds. Districts in order from above downward are: Scott Bay to Halls Harbour; Black Rock to Morden; Margaretville and Port George; Port Lorne to Hampton; Phinney Cove to Lash Cove.

Quaco catch in 1888 corresponds with disappearance of the mass from Kings County in 1886, which gives again two years for the rear to move from Minas Channel to the New Brunswick shore near Saint John.

In Figure 6, it can be seen graphically from the catches in the various districts how the herring were shifted from Grand Manan to Saint John, across to Annapolis, to Minas Channel and then back to Saint John, in the course of seven years, from 1877 to 1884.

That the herring should pass from the Saint John–Grand Manan circulation and later return to it implies a change in its relation to the water of the Bay on its east side. It would seem that from 1877 to 1881 the return flow to the Reversing Falls at Saint John of salt water to replace that mixed with the fresh was from Grand Manan rather than from the open bay to the east. This is shown by the drop in numbers of herring at Grand Manan, in the rise in their numbers near Saint John, and in their appearance in Kennebecasis Bay inside the falls. This condition ceased in 1882, to judge from the increase in numbers at Grand Manan and the decrease in Kennebecasis Bay. Only after two years, however, was the change pronounced enough to cause disappearance of the herring in Kennebecasis Bay and a marked decrease in their numbers in the Saint John outflow (winter of 1883–84). With this change, it can be presumed that, in correspondence with the usual contraclockwise circulation of water around basins in the northern hemisphere due to the Coriolis force, the return flow of salt water to the reversing falls would come in large part from the open bay to the east. This would bring into the Saint John outflow herring arriving there from the head of the Bay. It is of course possible that even when herring were passing from the outflow into the bay near Grand Manan, they were passing back into the outflow near Saint John. This would be a way in which the stock near Saint John may have been maintained from the beginning of the exodus.

While there is no evidence that the herring that reached the Nova Scotian shore and passed along the shore towards Minas Channel actually entered that Channel, there is some evidence that they passed to some extent into the water north of Isle Haute. The catches at Advocate rose suddenly in 1884 to five times the previous height and dropped as suddenly in 1886 (Figure 6 and Table V). The procession of herring was passing Isle Haute presumably from 1883 to 1886. It might be expected that part of it would go into the shallow water to the north and reach the Advocate shore. In Albert County farther north the catch more than tripled in 1885 and dropped rapidly in 1887 and 1888 (Figure 6 and Table V). Just where these were taken is uncertain, but this seems to have been due to invasion by some of the mass of large Quoddy herring.

The numbers of herring in the outflow continued very high for four years, doubtless with continuing arrivals from the northeast. The greatest amount (over 11½ million pounds) was taken in the third year. There was not much reduction in 1888, the fifth year. Thereafter, however, there was a rapid decline, the amount dropping 50 per cent each year for three years. This coincides with the disappearance of the winter herring inside the Quoddy region, and may be attributed as

for the latter to exhaustion of the stock through old age without significant recruitment.

MOVEMENT OUT OF THE BAY AND TO WESTERN NOVA SCOTIA

The mass of herring that left Grand Manan, beginning in 1877 and apparently continuing until 1881, has been shown to have appeared in strong force in Quaco in 1880 and on the bay shore of Annapolis County in 1881. For this, they must have passed from the Saint John–Grand Manan circulation eastward into the bay, making in each case a contraclockwise circuit around the bay, since the water in that part of the bay moves primarily southwestward toward the mouth of the bay. Any remaining in the southwestward movement would pass out of the bay. It might be expected that herring entered this oceanward circulation all the way from Grand Manan to Saint John during the period of somewhat more than four years in which they failed to be held in summer on the shoal mixing grounds outside Grand Manan. Herring that passed out of the Bay along this course would be in the contraclockwise circulation of the Gulf of Maine. In this they would pass southwestward along the Maine coast as far at least as Mount Desert. The presence of Cashe's Ledge out in the Gulf tends to make the water circulate from Mount Desert across the Gulf to George's Bank. It would then pass northeastward inside that bank and Brown's Bank to reach the Nova Scotian shore and complete the circuit back to the mouth of the Bay of Fundy. The Canadian statistics of herring catches can show only whether any of the mass that left Grand Manan reached this shore of Nova Scotia.

There are no records to show whether herring became more abundant on the Maine coast after the start of the exodus from Grand Manan, since yearly reports of catches were not being made. However, investigations of the fishery were made in 1879 and 1880, with a collection of statistics for the latter year, and the situation followed until 1883. Earll's report upon the same was submitted in 1884 and published in 1887 (Earll, 1887). He makes no mention of any particular abundance of herring at any place along the coast from Jonesport to Casco Bay. They had gradually increased over a period of twenty years up to 1879 at Casco Bay on the west. But at the east near Jonesport, where fish from the Bay of Fundy would first come, both weir-fishing on the shore and netting on the offshore spawning grounds had decreased from 1875 to 1880, until the number of vessels employed was less than half what it had been. It seems evident that the mass of Quoddy herring did not go west to the coast of Maine.

The courses of the herring fisheries from 1878 to 1890 for the Counties of Digby, Yarmouth and Shelburne at the western end of Nova Scotia (Figure 10) show that the take rose very abruptly in 1881 on the Digby coast next to the mouth of the Bay of Fundy. It remained high for three years and then dropped rather abruptly, which corresponds somewhat with the four years of abundance elsewhere. In 1889 there is another abrupt drop, which corresponds with the disappearance of the large stock at this time in the Bay of Fundy, presumably through old age. There is not as much indication of this course of events for the take of Yarmouth County and still less in that of Shelburne County. The detailed

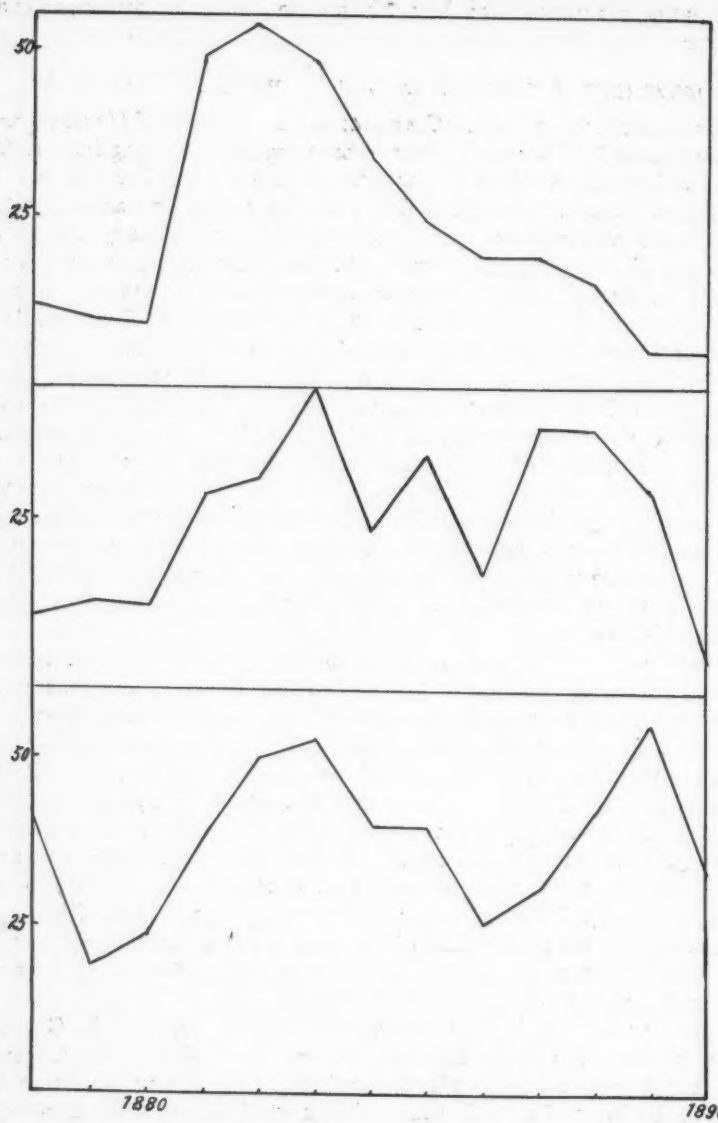

FIGURE 10. Large herring landed around southwestern end of Nova Scotia from 1878 to 1890, in hundred thousands of pounds. Above, Digby County; middle, Yarmouth County; below, Shelburne County.

takes for various sections of this shore from Digby inside the Bay of Fundy to Lockeport on the outer coast (Table VII), show abrupt increases in the catches in 1881 on outlying parts of the shore from near Digby to Yarmouth and Pubnico. There are less abrupt increases around Cape Sable as far as Shelburne but no farther. This is quite in accordance with expectations, since the shoal water associated with a sandy (Sable is French for sand) cape is somewhat of a barrier to movement. That the mass appeared the same year all the way from Cape Sable to Digby Gut indicates that part of it was being somewhat rapidly transported in deep water offshore. At the most outlying part of

TABLE VII. Herring in hundredweights for pickling landed in various parts of Digby, Yarmouth and Shelburne Counties, Nova Scotia.

	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890
Fundy shore (Broad, Gulliver and Shelving Coves)	0	*4,740*	*4,560*	*4,350*	*4,545*	3,900	2,580	2,400	2,340	0	300
Digby basin	2,100	2,550	*7,500*	*9,000*	*3,000*	900	600	1,200	660	0	0
Digby neck (Tiverton to Westport)	1,650	*13,608*	*12,444*	*10,800*	*6,000*	4,050	4,800	5,400	5,250	4,560	4,530
Head of St. Mary's Bay	0	105	60	*120*	*600*	*300*	*150*	60	24	0	0
Near Weymouth	420	*4,920*	*4,800*	*3,600*	*3,000*	2,850	2,250	1,800	600	0	600
Church Point and Meteghan	600	*6,465*	*7,575*	*6,750*	*4,350*	3,300	2,700	2,175	1,650	0	0
Cape St. Mary and Salmon River	600	*3,300*	*3,480*	*2,850*	*1,800*	1,680	1,650	1,800	1,650	0	0
Port Maitland to Yarmouth Bay	3,573	*10,335*	*7,830*	*11,709*	*8,415*	*16,200*	3,111	*11,700*	*11,700*	*7,878*	2,100
Yarmouth	2,790	3,132	*6,630*	*19,125*	5,805	*13,050*	*8,400*	*14,850*	*12,660*	*13,890*	1,290
Little River and Tusket	4,539	*9,069*	*9,990*	*8,862*	3,513	1,800	2,730	4,260	3,690	3,300	900
Argyle and Pubnico	1,188	*5,880*	*5,970*	*5,010*	*5,400*	*3,180*	1,956	*7,035*	*9,045*	2,775	180
Wood Harbour to Cape Island	2,700	3,600	*7,350*	*6,450*	*10,281*	*16,362*	*6,318*	*14,607*	*16,830*	*17,595*	5,655
Baccaro and Port La-Tour	5,100	*6,300*	*7,500*	*8,100*	*9,819*	*8,634*	1,854	2,865	3,900	4,533	1,590
Cape Negro to Port Clyde	3,735	*11,061*	*16,695*	*15,750*	9,207	6,510	6,963	3,879	5,508	7,251	3,660
Roseway to Shelburne	4,350	*9,150*	*9,000*	*10,500*	2,400	1,950	5,556	5,145	*8,457*	*11,196*	*10,170*
Jordan Bay and Ferry	2,400	1,275	900	1,323	1,362	654	1,065	375	642	2,952	3,105
Lockeport	5,400	4,500	4,800	3,900	5,490	4,500	3,000	1,650	2,400	6,000	6,600

this shore, and nearest to deep water, which is the outer part of Digby Neck from Tiverton to Westport, the catch rose abruptly in 1881 and dropped somewhat abruptly in 1884 and 1885, although not to the 1880 level. This four-year duration of a high catch corresponds with what was occurring in the Bay of Fundy, supporting the conclusion that this is part of the same phenomenon.

The inland districts show a delay in any clear effect from the arrival of the mass in 1881. Inside Digby Gut at Digby and inside Yarmouth harbour, there is no evident effect in 1881, but there is in 1882, and the peak of the effect is in 1883. At the head of St. Mary Bay, which is quite long and shallow, the peak is reached only in 1884. In general for Digby County, that is, from Digby to Salmon River, there is a decline shown after 1884 and a collapse in 1889. For Yarmouth County from Port Maitland to Pubnico there is varied fluctuation after the initial rise and there is an abrupt drop in 1890. Around Cape Sable there is much variation as if other stocks of similar size were masking any effect of the mass from Grand Manan. The collapse in 1889 and the abrupt drop in 1890 for parts of this shore agree in time with the passing away of the winter herring inside the Quoddy region and may similarly be attributed to exhaustion from old age of stock having little or no recruitment.

THE MOVEMENT AS A WHOLE

The two-year delay in reaching the full effect at Quaco, and something of the same on the Annapolis shore, indicates a great slowness in movement of the main mass well out of the Grand Manan–Saint John axis. This might be due to relatively dead water between that circulation and the circulation of the main part of the Bay of Fundy. Presuming this, the shiftings of the parts of the very large mass of herring that started to go from Grand Manan in 1877 were as follows (Figure 11): from 1877 to 1881, off the Charlotte County shore and toward Saint John; from 1878 to 1881, a small number into Kennebecasis Bay inside the Saint John estuary; a small number getting out into the main Fundy circulation in 1878 and reaching Quaco in that year and Annapolis County in 1879; the main mass passing out more slowly, the van getting into that circulation in 1880 and the rear in 1883. The van reached Quaco in 1880, Annapolis County in 1881, Kings County, N.S., in 1882 and back to the Saint John outflow in 1884. The rear reached Quaco in 1883, Annapolis County in 1884, Kings County in 1885, Quaco again and the Saint John outflow in 1887, with exhaustion there of this lot about 1889. Another part of the main mass passed out of the Bay of Fundy, presumably its van in 1880 and its rear in 1883. It is presumed that it circulated quickly in a contraclockwise direction around the deep northern basin of the Gulf of Maine to reach the southwestern extremity of Nova Scotia in a year's time. The van reached outlying parts in 1881 and the rear reached them in 1884. On this coast the mass penetrated slowly into the shallower water and the inlets and this lot was exhausted in 1889 and 1890.

The transformations made in the catches of herring in the various districts in a period of fifteen years are shown in the four maps of Figure 12. These show

the distribution of the herring catches throughout the region in 1876, 1881, 1886 and 1891, respectively.

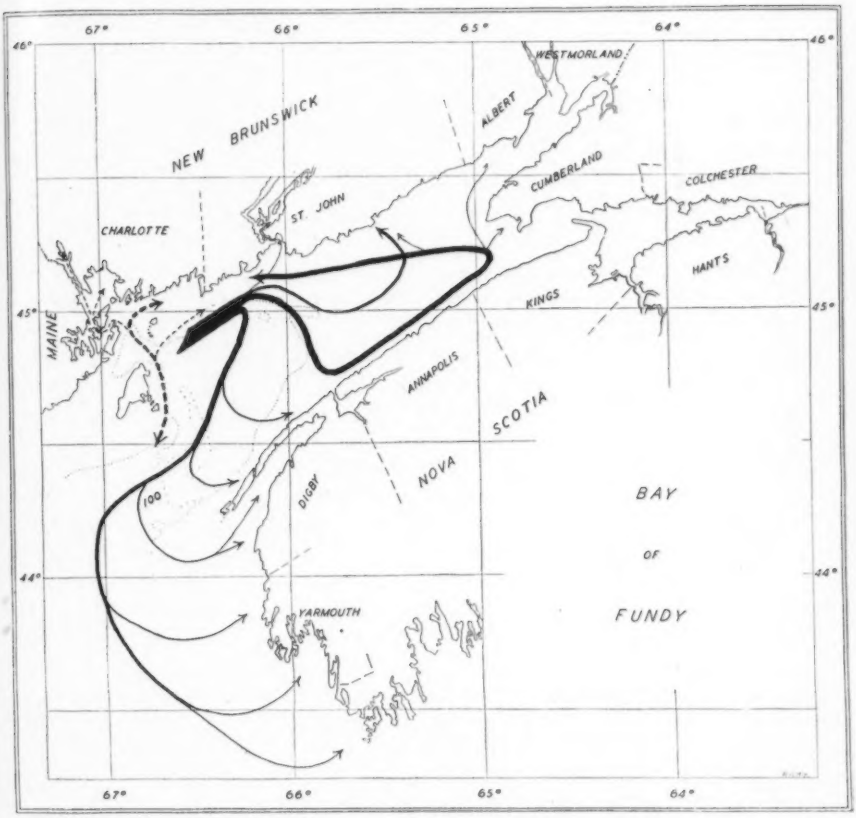

FIGURE 11. Seasonal movements (– – – – –) of large Quoddy herring, outside Island of Grand Manan in summer and to coast into Passamaquoddy Bay in winter. Long term movements (————) of these herring from 1877 to 1887 to Saint John, to head of Bay of Fundy and back, and to Nova Scotian coast as far as Cape Sable.

CIRCULATION OF THE FUNDY WATER

Since herring are clearly shifted by water movements, their movements in and near the Bay of Fundy will be in part and perhaps largely determined by the circulation of the water of the bay. This varies considerably with conditions, and the movement of the water near the surface where the herring are much of the time is particularly variable, being dependent upon wind and upon outflow of light water from rivers. Only a general picture can be given.

Although Dawson (1905, 1908) did not feel able to conclude from his current measurements that there is any general movement in the bay that is at

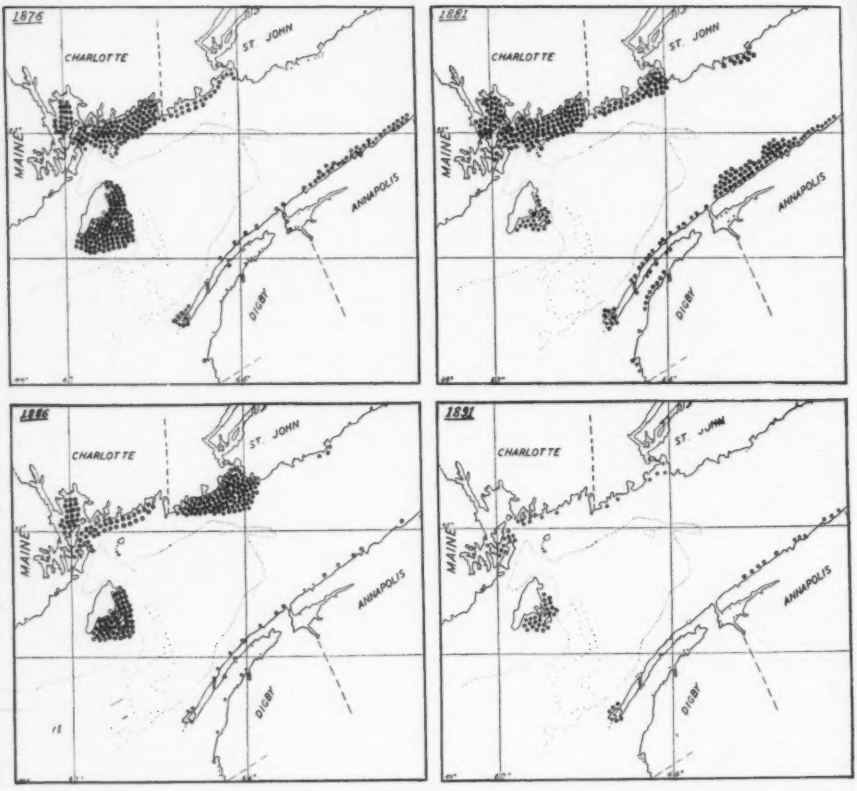

FIGURE 12. Landings of large herring around Bay of Fundy in 1876, 1881, 1886 and 1891. Each large dot represents 400 barrels of 300 pounds each.

all well marked, Mavor (1922) subjected his data to simple dynamic treatment and deducted from them that water moves into the Bay from the Gulf of Maine along the Nova Scotian coast, crosses the Bay from the Nova Scotian to the New Brunswick side between Digby and Saint John and flows out of the Bay to the east of Grand Manan. Craigie (1916) had shown that the water is considerably denser on the Nova Scotian side of the mouth than it is near Grand Manan, even to a depth of 40 fathoms, which is understandable only on the basis of movement inward near Nova Scotia and outward near Grand Manan. Mavor (1923) corroborated this, and found warmer and less saline water to be massed on the New Brunswick side of the bay from Cape Spencer east of Saint John outward, and to extend southward along the east side of Grand Manan. Also, Mavor (1922) demonstrated with drift bottles a circulation of the type indicated, with a rate of four or five miles per day from near the Nova Scotian shore above Digby Gut across to Saint John and along the New Brunswick

shore to Musquash, Chance Harbour, Lepreau, Seeley's Head, Letite and Campobello for a series put out somewhat inside the Digby–Saint John line on August 21 in 1919. At that time, no movement was shown to the Nova Scotian shore or farther into the bay on that side. A series put out on August 29 outside the Digby–Saint John line, from Point Lepreau to Gulliver Hole showed, for a considerable distance out from the New Brunswick shore, movement only westward and out of the bay, and with the usual rate. The returns from the rest of the series were so delayed as to indicate circulation around the outer part of the bay with some movement to the Nova Scotian shore. But, a short series put out on September 26 for 10 miles out from Brier Island at the mouth of the Bay on the Nova Scotian shore, showed movement only to and inward along that shore and for a distance of 70 miles to Port George at a rate of at least four miles per day. This was evidence that the heavy and more saline water moving in from the Gulf of Maine along the Nova Scotian shore either crosses to the New Brunswick side along the 50-fathom contour line to reach Saint John harbour and be mixed with the fresh water of the Saint John River, or continues to the head of the Bay to be mixed with the fresh water discharged into Minas and Cumberland Basins.

Later experiments with drift bottles put out in the Gulf of Maine and in the outer part of the Bay of Fundy on the New Brunswick side, reported by Bigelow (1927) and by Fish and Johnson (1937) have confirmed the above interpretation. In addition they showed movement from near the Maine and Massachusetts coasts to the Nova Scotian coast all the way from Cape Sable to Minas Channel and Advocate at the head of the Bay of Fundy. Our unpublished results (summarized by Bigelow) from drift bottles put out near the southwestern end of Nova Scotia from 1922 to 1926 show the water movements of that region. A series put out in the offing (about 35 miles) of Cape Sable on July 3, 1923, shows comparatively dead water there, as the depths and the character of the shore suggest. Two series put out on July 12, 1926, one out from Brazil Rock near Cape Sable and the other out from Cape Forchu near Yarmouth, show the contrast between the relatively dead water near Cape Sable and the inward-moving water near Yarmouth. While bottles of the line out from Brazil Rock continued to be picked up near Cape Sable for a couple of months (on September 9, one was found four miles south of Cape Sable), none of those of the line out from Cape Forchu were found near Yarmouth after five days, and the returns showed that the mass of the latter bottles had reached the offing of Brier Island at the mouth of the Bay of Fundy in seven days, which represents a movement inward of four miles per day. At that time they did not reach the Nova Scotian shore inside the Bay, but were evidently circling in the outer part of the Bay, as shown by comparatively slow rates for direct course to the places where they were first found, such as: the Bulk Head rip, east of Grand Manan on August 6; White Head, Grand Manan, on August 17; Nantucket Island, Grand Manan on August 30; Beaver Harbour, N. B., on August 30 and another on September 1. That some had worked into the inner half of the bay was shown by returns from Eatonsville and West Advocate at the head of the Bay on Sep-

tember 3 and 8 respectively, as well as by later returns from the shores of Kings and Annapolis Counties. They continued to be found in the outer Bay on both Nova Scotian and New Brunswick sides.

There are definite indications as to the effect of fresh-water discharge from the rivers on the extent to which the drift bottles are carried riverward. In 1919 (Mavor, 1922), three bottles reached Red Head on the east side of the entrance of Saint John harbour on August 29 in eight days after being put out within five miles of the Nova Scotian shore above Digby Gut. The discharge of the St. John River at Pokiok had been dropping from 17,300 sec.-ft. at the beginning of the month to 4,600 sec.-ft., and had been below 10,000 sec.-ft. for three weeks. In 1926, five bottles were found at Mispec, Sheldon's Beach, Black Point and the Negro Point breakwater, all near and at the entrance to Saint John harbour, from October 7 to November 10. These had been put out along the lines from Brazil Rock (two on July 12) and Cape Forchu (three on September 6 and October 13) on the Nova Scotian side of the entrance from the Atlantic Ocean to the Gulf of Maine. While the discharge of the St. John River had been increasing during October, it had been less than 5,000 sec.-ft. at the end of August, and had a mean discharge in September of 9,770 sec.-ft. The level of the St. John estuary, as measured at Oromocto, was below two feet in late August of 1919, and did not rise above 2.4 feet in the season of 1926 until October 17. In the season of 1932, the mean monthly discharge of the St. John River did not drop below 18,700 sec.-ft., and the level of the estuary was as low as two feet at Oromocto only for a week in the middle of September. No drift bottles were found that year at or near the entrance to Saint John harbour, although they were picked up in the offing, for example 11 miles southeast of the Lorneville breakwater.

The inner Bay of Fundy, inside the line from Saint John to Digby, is somewhat shallower than the outer, has relatively little fresh water discharged into it along its sides which are quite straight and has its water very thoroughly mixed through heavy tidal action. For it, there are neither direct current measurements nor results from drift bottles set out in lines across it. Its circulation is to be inferred from knowledge of the density of its water from place to place that shows the hydrodynamic forces that are in operation, as well as from the behaviour of drift bottles and other drift material that enter it from without. Sections in June across the inner Bay (Watson, 1936) show its water to be almost uniform in character from top to bottom at any one place, owing to the heavy mixing, but to decrease in salinity and increase in temperature going inwards or across from the Nova Scotian to the New Brunswick shore. This massing of light water at the head of the bay and on the New Brunswick side means that the water of the inner bay circulates by moving on the whole inward and to the New Brunswick shore near the bottom and outward and to the Nova Scotian shore near the surface. Also, as a result of the Coriolis force, there is movement from top to bottom both inward along the Nova Scotian and outward along the New Brunswick shore. The main tidal movement of water inwards past the head of the bay is through Minas Channel into the extensive Minas Basin. Minas Channel is tortuous and does not permit the Coriolis force to separate horizontally the

inward movement of the heavier water from the outer movement of the lighter water. Consequently, the surface circulation is outward all the way across the channel. Drift material carried into the inner Bay along the Nova Scotian shore is stopped at the mouth of Minas Channel and collects there. The mass of drift material there collected, which frequently contains lobster buoys of most diverse origin, is locally known as the "cedar swamp". Drift bottles that enter the inner bay are thus concentrated along the Nova Scotian shore toward Minas Channel, as shown in Figure 8. Their virtual absence from the New Brunswick shore is noteworthy. In 1926, with relatively dry conditions, two drift bottles were found inside Minas Basin and two in Chignecto Channel leading to the Cumberland Basin; but in the relatively wet year of 1932 none were found in either of these places. Fish and Johnson (1937) showed movement into Minas Basin in their figures, but, as is evident from study of the records in their tables, this was clearly due to a misconception as to the location of Harbourville, which is outside Minas Channel, not inside Minas Basin. While drift material tends to collect at the mouth of Minas Channel and not penetrate it, there will be movement from it which will be mainly from its north side to and along the New Brunswick side of the bay. Such will cross the entrance to Chignecto Channed. Only in the relatively dry season of 1926 were any drift bottles reported as entering this Channel, and none have been reported from the Cumberland Basin. There is clearly very little surface movement either into the Channel or to the New Brunswick shore as far as Cape Spencer near Saint John. This is in accordance with the inference from the hydrographic sections that the surface water moves from the shore across the Bay.

Near Saint John, the circulation of the water is dominated by the heavy mixing of salt water with fresh water at the reversing falls inside the harbour. The salt water for the mixing will be drawn both from the relatively light water that is passing outward past Cape Spencer from the inner Bay, and also from the heavier water that moves across the Bay from Digby Gut toward Saint John. The mixed water from the Reversing Falls passes outward from the harbour and along the shore toward Grand Manan, and becomes progressively more salt with further mixing along this course. As shown by the drift bottles, surface water from the open Bay passes into this stream and to the places of shallow mixing along the shore. This was shown particularly well by the drift bottles put out along various lines across the outer part of the bay in 1919 (Mavor, 1922). Of these, 19 were found between Cape Spencer and Point Lepreau, 15 from Point Lepreau to Letite, seven from Letite to Campobello Island, one at the Wolves Islands, four at Grand Manan and two in Washington County, Maine. The bottles put out off the southwestern end of Nova Scotia in 1926 gave a fair number to show this movement (Figure 7). Of those put out in 1932 in relation to the region, that is, around Grand Manan and southwestward along the Maine coast, seven were found between Cape Spencer and Point Lepreau, six from Point Lepreau to Letite, one at the head of Passamaquoddy Bay, six from Letite to Campobello, 12 at Grand Manan, and seven in Washington County, Maine.

In addition to such surface movement of water into the Quoddy region from

the east and from the circulations of both inner and outer Bay of Fundy, deep water from the mouth of the bay passes between Grand Manan and the Wolves Islands to the main entrance to Passamaquoddy Bay at the northern end of Campobello island. That entrance, Quoddy River, is quite deep and irregular, and has heavy tidal action. In it the fresh water discharged into Passamaquoddy Bay from the St. Croix, Magaguadavic and Digdeguash Rivers is very thoroughly mixed with the heavily saline water available at a considerable depth just outside its mouth. Such consumption of the deep water causes it to be renewed by inflow from the Gulf of Maine. The passage along this course of much deep water from the Gulf is evident from the frequent occurrence at the surface in the Quoddy River of deep-water forms, such as the copepod *Calanus* ("red feed" of the fishermen) and the Euphausiid *Meganyctiphanes* ("shrimp" of the fishermen), that do not breed successfully in the Bay of Fundy, but do so in the Gulf of Maine. These forms are sometimes in such vast numbers as to be cast up on the beach in windrows. In the wet summer of 1911, before there was much control of the discharge of the St. Croix and Magaguadavic Rivers for power purposes, the "shrimp" were to be seen just inside Passamaquoddy Bay and were taken from the stomachs of fish captured in weirs at St. Andrews. This inward movement of deep water serves to explain the shifting of the large spent herring from outside Grand Manan to Campobello and eastern Charlotte County, and even into Passamaquoddy and Oak Bays, when they drop into deepish water during the winter season.

DISCUSSION

The movements of the herring in relation to the land and bottom are the resultant of their proper movements in swimming through the water and of the movement of the water in which they are swimming. Evidence fails for the idea that they are able to navigate, that is, to steer a horizontal course in relation to the shore or the bottom, except when quite close to it. They clearly lead along the shore when they are quite near it and they also head and swim upstream when in a current and close to the bottom. Since they are for the most part some considerable distance from the shore and the bottom, their swimming is on the whole not earth-directed. They orient in relation to other things, such as food animals in the water near them. Being oriented in various directions, any set or circulation of the water in which they are swimming, even though quite slow, is apt to effect a shifting of them from one district to another.

Along a coast with discharge of fresh water from rivers, there is a complex differential set or circulation of the water varying with depth, as a result (1) of the relative lightness of the fresh water, particularly when warm in summer, and (2) of the way in which it is mixed with the heavier salt water largely by tidal action. For example: If fresh water flows out over the surface of a bay, it will carry with it some of the salt water just below and create at a deeper level a return current toward the stream from which it has come. When the fresh water spreads to the shore of the bay, it will be mixed by tidal action with the

salt water below. The mixture as of intermediate density flows out into the bay, while the fresh water at the surface flows to the shore above it and the salt water flows to the shore below it.

In what direction a mass of herring will be shifted depends upon the depth at which they are swimming and upon the local and temporal circulation of the water at that depth. During the day herring are down below the surface a distance that varies with size. They come toward or to the surface after dark. There is as yet no precise knowledge of this localization of herring in depth by light, that is, of the proportions of the 24-hour day during which they are at particular depths below the surface, and this clearly varies, not only with the size of the fish, but also with the season and with the weather. Nor have we precise knowledge of the circulation of the water at different distances below the surface in the different localities, which also varies with season and with weather.

Under these circumstances, all that can be done is to attempt to relate the facts about the occurrence of the fish, as shown by their capture, to what is known of the circulation of the water. Capture of the herring in stationary weirs provides not only precisely localized data on their occurrence, but also data from continuous operation through a long season. The same cannot be said for other types of gear. The weirs fail to show occurrence of the fish when not moving rather near the shore. The large herring were commonly taken with gill-nets, which could be set anywhere rather easily. As their growth was almost negligible after reaching spawning size, they could be taken effectively in nets of standard mesh. Throughout the whole period from 1876 to 1895, there was a steady demand for them in the pickled state, the stated price starting at $4.00 a barrel and ending at $4.50. Pickling could be readily done anywhere along the coast with supplies of salt and of barrels. In addition there was sale for them in both the fresh and frozen state. For these reasons, the statistics of the local fisheries for them are particularly reliable as representing their distribution throughout the period.

A combination of circumstances has permitted us to trace the large mass that left the Quoddy region. The numbers of adult herring related to that region is outstandingly large in comparison with the rest of the Bay of Fundy and the Gulf of Maine. This is the result of the young being concentrated into the region and provided with an abundance of food that is brought by the circulation in from the Gulf of Maine. When the exodus occurred, the sardine industry was developing, which prevented much addition to the accumulated Quoddy stock. For these reasons, the very large mass which left the region over a four-year period, was conspicuous wherever it went and as long as it lasted.

The slowness with which the mass was shifted is remarkable. This can be understood from a knowledge of the circulation. In general, with sloping bottom near a coast any herring out from a river mouth or the shore will be exposed to three or four conditions with depth. Out from the shore where tidal mixing occurs, there will be almost stationary water near the bottom, a set toward shore or a shoal at a higher level, a set from shore or a shoal at a still higher level,

and near the surface a set toward shore or a shoal. These tend to cancel each other.

That great reduction in the number of spawning adults in the Quoddy region did not affect the numbers of young can be understood from the probability that the young are concentrated there from the circulation of the larvae around the Gulf of Maine and Bay of Fundy system, that is, they are drawn from an extensive area, throughout which herring breed. The larvae in this region do not seem to be localized by light until approaching metamorphosis. They are at all depths, that is, generally distributed both vertically and horizontally. When they become clearly sensitive to light, they approach the surface and are carried into the region with the superficial set of the water to places of greatest mixing. Doubtless the original very heavy concentration of adults outside Grand Manan provided vastly more eggs and young than could survive. Also, concentration of both eggs and young made these particularly susceptible to predation. It is conceivable that the present greatly reduced, but still large number, of adults there produces as many young at the stage of concentration in the region as were produced by the very much greater numbers there before the sardine industry developed.

Reduction of the numbers of older fish by an intense fishery for various ages of fish is a general result that has been frequently observed. That this should affect the growth of the younger fish is also something that is being found of rather general occurrence. This is to be expected if there is a limited and common stock of food for the various ages. The Quoddy herring have roughly three sizes of food, brought planktonically into the region. These tend to be distributed appropriately in the region for the various sizes of herring, the small copepods being chiefly in Passamaquoddy Bay, the large copepods at the mouth of the Bay and the shrimps (Euphausiids) farther out. There is, however, much overlapping in feeding as well as in distribution. That food is a limiting factor for growth of the fish, that is, for production of pounds for capture, is shown by the great variations in fatness of the rapidly growing fish throughout the region (Battle *et al.*, 1936). Only in the inlets related to the main Quoddy passage into Passamaquoddy Bay does there seem to be any surplus and that only for short periods. There are indications that to a considerable extent the food animals are brought into the region and held there until they are consumed.

It may be said that the heavy fishing for the young has resulted in a very efficient use of the food available in producing pounds of herring. There is no indication that the food brought in fails to be consumed. It is largely devoted to the rapidly growing, immature fish.

The conditions back of the shifting of the large Quoddy herring toward Saint John and out into the Bay of Fundy, beginning in 1877 cannot be elucidated to any great extent. They are evidently peculiarities in river discharge, but we have no records of discharge for that period and only a few records for rainfall. The abundance of salmon has been found to be related to rainfall and there was a very marked change in abundance of Maritime salmon from very

high in 1873 and 1874 to lower than ever before in 1880 and 1881 (Huntsman, 1937).

The records of rainfall give some indication of the changes in the 1870's that took place in the levels of the water in the rivers to affect salmon abundance and in the discharge of fresh water into the Bay of Fundy to affect the distribution of the herring. The main discharge is through the Saint John River, with a drainage basin of about 21,500 square miles. It is stored at tidal level in the 80-mile-long estuary of the river between Saint John and Fredericton. From this estuary, it passes out slowly through the narrow mouth at the Reversing Falls, where it is mixed with about twice its volume of salt water. In the Bay, along the course of its outflow from Saint John to Grand Manan the mixture is mixed with a vastly greater volume of salt water so that there is very much circulation of water through the region to transport the herring. The average rate of discharge of fresh water into the Bay of Fundy is 55,400 cu. ft. per sec. and of this 33,100 cu. ft. per sec. comes from the Saint John River (Watson, 1936). For the period from 1870 to 1885, no discharge records are available, but the precipitation at Saint John and Fredericton was being recorded. In Figure 13, have been plotted for these two places the changes in rainfall from year to year during the period. Since the herring are active and up in the water during the warmer part of the year, they are more apt to be affected by discharge during that period. The precipitation for November to April, May to July, and August to October are shown separately for each year.

The exodus of large herring from Grand Manan started in the summer of 1877, for which year the local officer reported "a gradual falling off in quantity with an extraordinary leanness in quality", and this at their spawning time when they are approaching shore and usually fat. It will be seen in the figure that the summer rainfall declined from 1872 to 1877, and that there was not much recovery from this low point until 1881. The effect of a greatly reduced summer circulation would be to move more or less of the stock toward Saint John. This would show mainly in the take of herring the next year. The four years of comparative drought in the summer from 1877 to 1880 showed in low takes of herring at Grand Manan from 1878 to 1881. Although the rainfall at Saint John and Fredericton cannot be considered to represent the discharge of the river, whose very extensive drainage basin is largely north of Fredericton, the facts support the idea that the shifting of large herring from Grand Manan was the effect of unusually low discharge from the Saint John River.

With a lessened Saint John outflow, movement of surface water from the Bay of Fundy to the outflow for the mixing would be more and more limited to the vicinity of Saint John. This would bring more and more of the water between Saint John and Grand Manan into the general contraclockwise circulation of the bay, with perhaps much intermediate dead water between the two systems. With four dry years, there would be continued leakage of the large Quoddy herring out into the circulation of the Bay, doubtless with steady return of such parts of the mass as reached the Saint John outflow near Saint John from

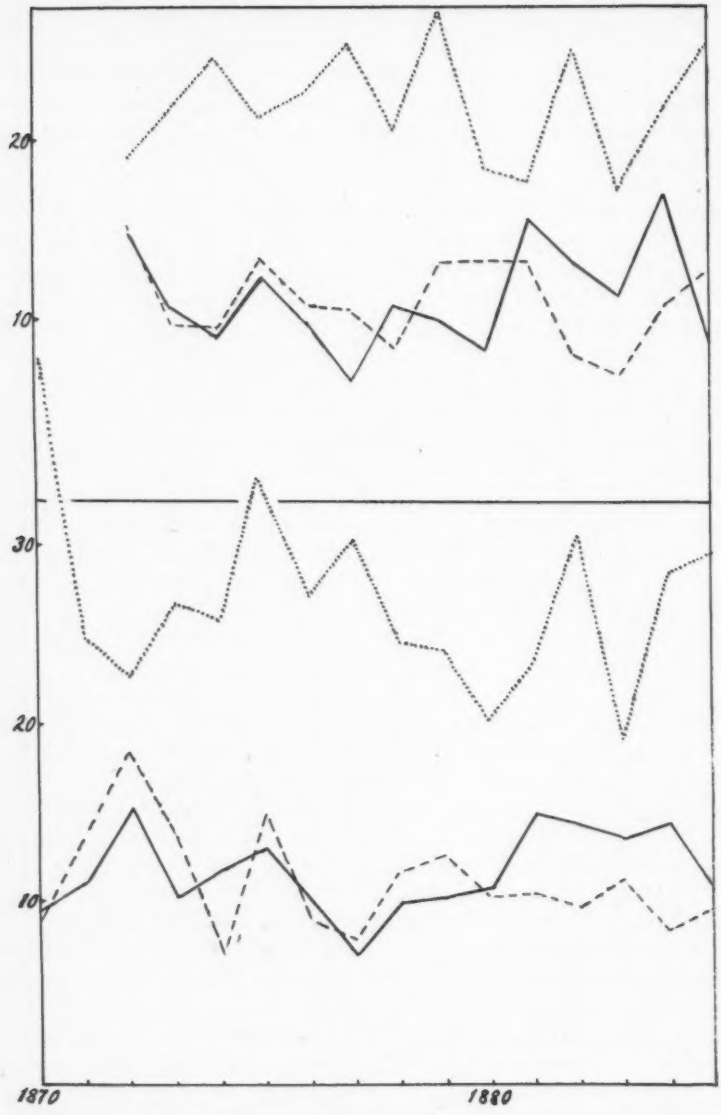

FIGURE 13. Precipitation in inches at Fredericton (above) and Saint John (below), N. B., for November to April (. . . . .), May to July (————) and August to October (– – – – –) for the years from 1870 to 1885.

the northeast. The graduation in effect from Saint John outwards is shown by the years in which the exodus from Grand Manan showed up in the various fisheries. These were: Kennebecasis, strong from 1878 to 1881, weak in 1882 and 1883; Quaco, weak in 1878 and 1879, strong from 1880 to 1883; Annapolis County, doubtful in 1878 and 1879, strong from 1881 to 1884; Digby to Yarmouth, strong from 1881 to 1884.

CONCLUSIONS

The facts seem to warrant the following conclusions:

The large herring of the Quoddy region are shifted seasonally by the currents that vary with depth and that are related to the fresh water discharged from the rivers. With rising temperatures in the spring they rise from the bottom and are shifted outward past Grand Manan, where the outflow of light water thins out on spreading into the Gulf of Maine. With falling temperature in autumn they sink into deep water and are shifted toward the coast and the estuaries where the fresh water is mixed deeply with the sea water.

In the late 1870's, low rainfall resulted in shifting of a large part of the herring toward Saint John harbour for four years, some even going inside the harbour to Kennebecasis Bay. To a very considerable extent these herring entered the general circulation of the Bay of Fundy and were carried in the course of years to the New Brunswick coast eastward of Saint John and to the Nova Scotian coast from Cape Sable to Minas Channel. They did not enter Minas Channel, but were carried thence along the New Brunswick coast back to the Saint John outflow. They became exhausted through age and otherwise from 1888 to 1890.

Development of the canning of small herring as sardines, starting in 1875, resulted first in the disappearance in 1877 of the fat Quoddy River herring, which were found close to the location of the first factories. A second effect was an increase and a later decrease in the number of medium herring. A third effect was an ultimate great decrease in the numbers of the large herring by 1890. A fourth effect was an increase in the numbers and an extension of the distribution of the small herring.

SUMMARY

Study of the pertinent accounts and records shows the following for the large herring of the Quoddy region at the mouth of the Bay of Fundy when they were very abundant in the latter part of the 19th century.

In the summer they were to be found in the shoal water outside Grand Manan, whence they approached the southern end of that island in spawning during the late summer. Sinking into deeper water in the fall, they were gradually shifted by the deep return current to the deep mixing places at the mouth of Passamaquoddy Bay, chiefly in the Quoddy River, reaching Campobello early in October, getting as far east as Point Lepreau in early December and extending into Passamaquoddy Bay where they remained till late in the spring. Rising somewhat in the spring, they were shifted back to Grand Manan,

but a small proportion would be so far inland in Oak Bay off the estuary of the St. Croix River as to mature rapidly in the warmer water and spawn there in the spring.

The largest part of the fresh water that goes into the mixing in the central part of the Quoddy region where the annual shifting of the large herring is determined, comes, not from the rivers discharging into Passamaquoddy Bay, but from the Saint John River to the northeast along the coast. Wet years in the early 70's provided much water for this mixing, but dry years in the late 70's provided little. With the change starting in 1876 or 1877, the large herring became shifted over from the usual movement between Grand Manan and Quoddy River to movement between Grand Manan and the Reversing Falls at Saint John, where occurs the heavy primary mixing of the Saint John River water. Along this line they failed to return to Grand Manan, with a shallow outflow of mixed water. This movement continued for fully four years or more (1877–81), during which period herring were unusually abundant in the Saint John outflow and in Kennebecasis Bay inside the Reversing Falls.

The weakness of the circulation between Grand Manan and Saint John resulted in steady shifting of more and more of the mass of large herring offshore into the Bay of Fundy during the four years. In the general contra-clockwise circulation of the Bay, parts of the mass took three different courses, giving three processions of herring. From van to rear each procession took four years to pass any given point along its course. While a small part of the mass moved quickly out into the Fundy circulation, most of it took two years.

Of the three processions, the most northerly reached Quaco on the New Brunswick shore in 1880 and passed in 1883, doubtless returning quickly back to what remained off Saint John. The intermediate procession reached the Annapolis County shore in 1881 and passed in 1884, reached the Kings County shore in 1882 and passed in 1885, returned westward to the New Brunswick shore, which it reached in 1884 and passed at Quaco in 1887. With changed conditions of greater outflow of Saint John River water, it entered that outflow and remained there until exhausted through age and otherwise from 1888 to 1890.

The most southerly procession passed out of the Bay of Fundy and around the northern part of the Gulf of Maine to reach the southwestern extremity of Nova Scotia in 1881, from Digby to Cape Sable. It gradually worked in over the shallows and into the inlets in from one to three years. It passed the outlying portions in 1884 and became exhausted in 1889 and 1890.

Contemporaneously with these shiftings of the large Quoddy herring, the use of the small herring for sardines, as readily taken far inland in the Quoddy region, developed somewhat gradually, starting at Eastport, Maine, in 1875. The first effect was on the very fat Quoddy herring, which were from the very fat sardines of the inlets near Eastport related to the Quoddy River. They disappeared from the River or passage in 1877 and have not been taken since. The second effect was to make the sardines more abundant by having fewer stringing herring as well as fat Quody herring locally. The third effect was to

increase the number of stringing herring farther out in the region. Finally, and not clearly separated from shifting of the stock, there was marked decrease in the numbers of the large herring, when with reduced recruitment the accumulated stock became exhausted with age from 1889 to 1891, the winter fishery disappearing. Further development of the sardine industry reduced the numbers of stringing herring somewhat, increased the numbers of sardines still further and further reduced the numbers of large herring. This condition of very many sardines, rather many stringers or fat herring and very few adults, has prevailed since, with fluctuations, some of which have been from change in intensity of fishing.

REFERENCES

Andrews, M. J. C. (1874). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1873.*

Battle, H. I., A. G. Huntsman, A. M. Jeffers, G. W. Jeffers, W. H. Johnson and N. A. McNairn, (1936). Fatness, digestion and food of Passamaquoddy young herring. *J. Biol. Bd. Canada,* **2**, 401.

Brown, Jas. (1884). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1873, 1877, 1883.*

Bigelow, H. B. (1927). Physical oceanography of the Gulf of Maine. *Bull. U. S. Bur. Fisher.,* **40**, 511.

Billings, R. (1905). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1904.*

Brown, Jas. (1844). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1883.*

Carty, W. T. (1886). Quoted under Annapolis County, Nova Scotia. *Ann. Rep. Dep. Fish. Canada, 1885.*

Cunningham, B. L. (1878, 1882, 1885). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1877, 1881, 1884.*

Dawson, W. Bell (1905). The currents at the entrance of the Bay of Fundy, 17 pp. Dep. Mar. and Fish., Ottawa.

(1908). Tables . . . of the currents . . . in the Bay of Fundy . . ., 15 pp. Dep. Mar. and Fish., Ottawa.

Earll, R. E. (1887). The frozen-herring industry. *In* The Fisheries and Fishery Industries of the United States, Sect. V., vol. 1, p. 439.

Fish, C. J. and M. W. Johnson (1937). The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. *J. Biol. Bd. Canada,* **3**, 189.

Gosline, S. (1882). Quoted under Kings County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fisher. Canada, 1881.*

Hachey, H. B. (1934a). The replacement of Bay of Fundy waters. *J. Biol. Bd. Canada,* **1**, 121.

(1934b). Movements resulting from mixing of stratified waters. *Ibid.,* 133.

(1935). Tidal mixing in an estuary. *Ibid.,* 171.

(1939). Hydrographic features of the waters of Saint John harbour. *J. Fish. Res. Bd. Canada,* **4**, 424.

Hodgson, W. C. (1934). The natural history of the herring of the southern North Sea, being the Buckland Lectures for 1933, London: Arnold & Co.

Huntsman, A. G. (1919). Growth of the young herring (so-called sardines) of the Bay of Fundy. Canadian Fisheries Expedition, 1914–1915, p. 165. Ottawa.

(1934), Herring and water movements. *In* James Johnstone Memorial Volume, p. 81. Liverpool.

(1937). The cause of periodical scarcity in Atlantic salmon. *Trans. Roy. Soc. Canada,* **31**, Sect. V, 17–27.

Lord, J. M. (1885). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1884.*

MAVOR, J. W. (1922). The circulation of the water in the Bay of Fundy. Pt. I. Introduction and drift bottle experiments. *Contr. Canad. Biol.* **1**, 103.

(1923). The circulation of the water in the Bay of Fundy. Pt. II. The distribution of temperature, salinity and density in 1919 . . . *Ibid.*, 355.

MCLAUGHLIN, W. B. (1872, 1878, 1883, 1885, 1889, 1891). Quoted under Charlotte County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fisher. Canada, 1871, 1877, 1882, 1884, 1888, 1890.*

MOORE, H. F. (1898). Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. *Rep. U. S. Comm. Fish, Fisheries, 1896,* **22**, 387.

O'BRIEN, J. (1878, 1882, 1883, 1885, 1889, 1891). Quoted under St. John County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1877, 1881, 1882, 1884, 1888, 1890.*

PERLEY, M. H. (1851). Report upon the fisheries of the Bay of Fundy. *Journ. House Assembly, New Brunswick, 1851,* App. CXXIX.

PRATT, J. H. (1890). Report on the fisheries of the County of Charlotte, New Brunswick, for the year 1889. *Ann. Rep. Dep. Fish. Canada, 1889,* 119.

(1892). Annual Report on the fisheries of district no. 1, New Brunswick, for 1891. *Suppl. I, Ann. Rep. Dep. Fish. Canada, 1891.* 63.

(1894). Report on the fisheries of district no. 1, New Brunswick, comprising the County of Charlotte for the year 1893. *Ann. Rep., Dep. Mar. and Fish. Canada, 1893,* 174.

(1905). Report on the fisheries of district no. 1, New Brunswick, comprising the counties of Charlotte and St. John, for the year 1903. *37th Ann. Rep. Dep. Mar. and Fish. Canada, 1904.* Fisheries, App. 4, pp. 96–101.

ROURKE, E. V. (1888 to 1893). Quoted under St. John County, New Brunswick, in Inspectors' Reports. *Ann. Rep. Dep. Fish. Canada, 1887* to *1892.*

SKILLEN, W. E. (1875 to 1887). Quoted under St. John County, New Brunswick, in Inspectors' Reports. *Ann Rep. Dep. Fisher. Canada, 1874* to *1886.*

VENNING, W. H. (1884). Report of Inspector of Fisheries for the Province of New Brunswick. *Ann. Rep. Dep. Fish., 1883,* 67.

WATSON, E. E. (1931). Water movements in Passamaquoddy Bay. *Ann. Rep. Biol. Bd. Canada, 1930,* 31.

(1936). Mixing and residual currents in tidal waters as illustrated in the Bay of Fundy. *J. Biol. Bd. Canada,* **2**, 141.